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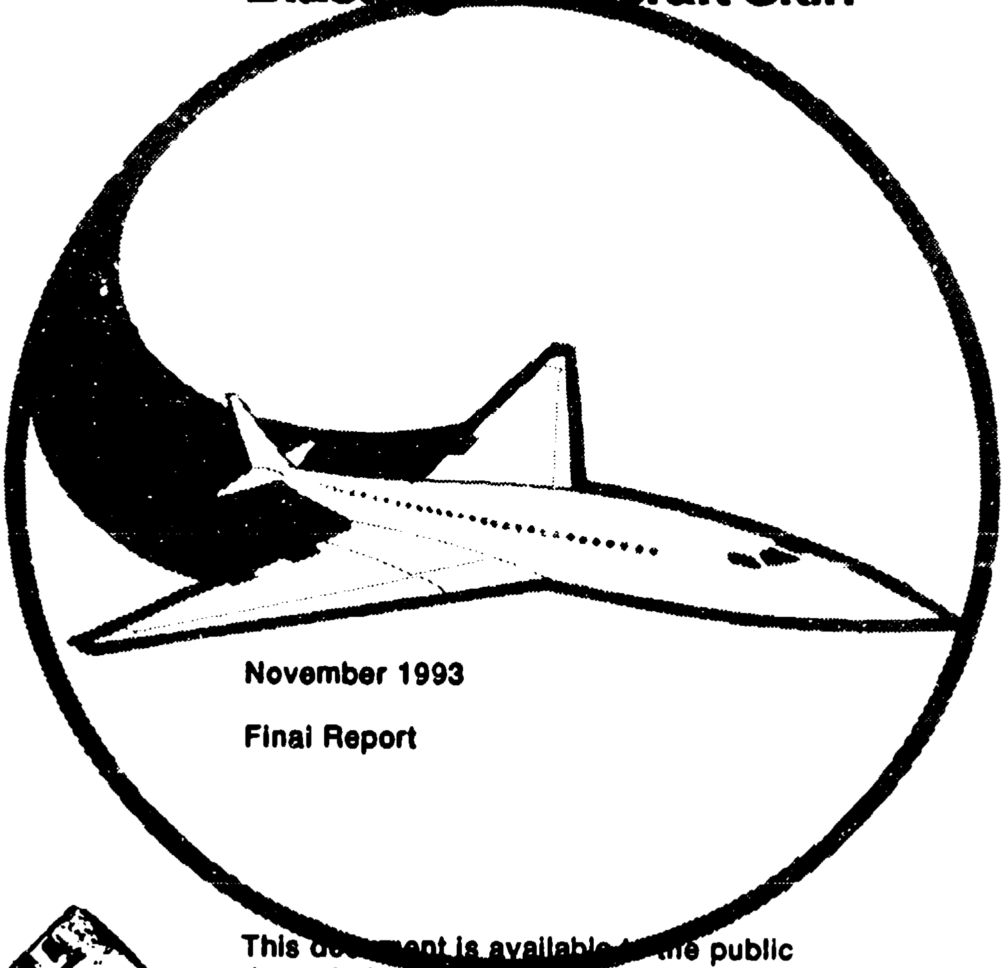
FAA Technical Center
Atlantic City International Airport,
N.J. 08405

Effects of Plastic Media Blasting on Aircraft Skin



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Final Report

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16. Abstract

The use of methylene chloride chemical solvents in aviation paint removal is becoming increasingly unacceptable in view of restrictive Environmental Protection Agency (EPA) regulations. A readily available alternative, plastic media blasting (PMB), must be examined for its effects on the thin aluminum used as skin material in civilian aircraft. This study examines the effects of plastic media blasting or the crack propagation rates of 2024-T3 aluminum in alclad of 0.032, 0.040, 0.050 inch thickness, and in anodized of 0.032, 0.040, and 0.050 inch thickness. A technical search was performed for the following topics: (1) fatigue crack growth (FCG) rate comparison between PMB and chemical stripping, (2) effects of heavy particulate contamination on the fatigue life of aircraft skin, (3) acceptable level of contamination in the plastic media, (4) effects of multiple strippings on FCG, (5) maximum number of strippings allowed, and (6) specifications of controlled parameters to safely operate a PMB system. Fatigue crack propagation tests, Almen strip tests, Scanning Electron Microscope (SEM) photography, and surface toughness measurements were conducted. The results of the technical search and the tests performed are presented, as well as supplementary Almen strip arc height data. This study also presents an overview of nine alternative aviation paint stripping methods in terms of paint stripping effectiveness, substrate damage, environmental impact, health impact, and cost.

17. Key Words Plastic Media Blasting Fatigue Crack Growth, Almen Strips, Surface Roughness, SEM Photographs, Analytical Methods, Blast Parameters, Residual Stress, Paint Removal Methods		18. Distribution Statement This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161	
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Executive Summary

The usual aviation paint removal method of using a methylene chloride chemical solvent is becoming increasingly unacceptable in view of restrictive Environmental Protection Agency (EPA) regulations. A readily available alternative, plastic media blasting, must be examined for its effects on the thin aluminum used as skin material in civilian aircraft. Specifically, it must be determined whether paint stripping with plastic media will increase the fatigue crack growth rate of aluminum aircraft skin structure. This study examines the effects of plastic media blasting on the crack propagation rates of 2024-T3 aluminum in surface treatments and thicknesses of concern to the Federal Aviation Administration. These surface treatments and thicknesses of 2024-T3 aluminum are alclad material in 0.032, 0.040, 0.050 inch thicknesses, and anodized material in 0.032, 0.040, and 0.050 inch thicknesses.

A technical search was performed for the following topics: (1) fatigue crack growth (FCG) rate comparison between PMB and chemically stripped aluminum, (2) effects of heavy particulate contamination on the fatigue life of aircraft skin, (3) the acceptable level of contamination in the plastic media,(4) effects of multiple stripping on FCG, (5) maximum number of strippings allowed, (6) specifications of controlled parameters for safe operation of a PMB system. This search provided valuable information on plastic media blasting test results for other materials and aluminum of various thicknesses and surface treatments. Current industry testing and performance standards were obtained. These standards include user specifications developed independently by several airframe manufacturers for material thicknesses greater than those being studied here. An analytical method was obtained, from Air Force Project Report 8TS084 (reference 12), which relates Almen strip arc height with the depth and amount of residual stress induced by the blast. However, test data specific to the subject materials being studied herein were difficult to obtain due to previous testing emphasis on different aluminum alloys, larger thicknesses, and bare rather than alclad or anodized 2024-T3 aluminum.

A test program was performed to supplement the technical search with directly applicable data. The program included residual stress examinations (Almen strip arc heights), scanning electron microscope (SEM) photographs, surface roughness measurements, and ASTM E 647 "Constant-Load-Amplitude Fatigue Crack Growth Rates Above 10^{-8}m/Cycle" tests. The blasting parameters were selected to be aggressive in order to obtain worst case results. The subject PMB process parameters on the following page.

BLAST SPECIFICATIONS	
Mass Flow Rate	900 lb/hr
Media Type	Type II
Media Size	30/40 Mesh
Air Pressure	35 psi
Nozzle Distance	12 inches
Nozzle Angle	90 degrees
Nozzle Diameter	0.50 inch
Media Purity	99.95%

Figure 1.0 Blast Specifications

The results of this test program are presented and discussed. After performance of the arc height measurements, the 2024-T3 anodized aluminum showed greater residual stress levels than the 2024-T3 alclad material. Both samples, anodized and alclad, with a 0.032" thickness, exceeded the industry's allowable arc height of 6 mils after the first blast cycle. But the 0.040" and 0.050" thick samples remained below the allowable arc height after the fourth blast cycle. The SEM photograph and surface roughness measurements showed that the alloy surface (core) was still intact. The corrosion protection coatings were roughened, especially in the alclad case. The maximum roughness (Ra) value belonged to the alclad 0.050" thickness material, with a measurement of 263.23 micro-inch; this is below the allowable 350 micro-inch (according to Boeing specification). The maximum percentage loss in anodized layer thickness was 24 percent for the 0.040" thickness specimen, while the maximum percentage loss for the alclad layer was 81 percent for the 0.050" thickness. The fatigue crack growth rates in the 2024-T3 anodized aluminum specimens were unaffected by the plastic media blasting. On the other hand, the fatigue crack propagation rates of the 2024-T3 alclad aluminum samples were significantly increased after the samples were subjected to the same stripping process. For example, the crack length significantly increased at a lower life cycle (more than 50 percent lower life cycle in three cases) when compared to its control counterpart and the fatigue crack growth propagation rates ranged from 1.05 to 4.09 times those obtained for the untreated samples at intermediate stress intensities. This change in crack growth rate is attributed to surface damage, including thickness reduction, and residual stress, caused by the of plastic media blasting process combined with the selected aggressive parameters.

Nine alternative paint removal methods were compared according to the following criteria: paint stripping effectiveness, substrate damage, environmental impact, health impact, and cost. The alternative technologies considered were blasting with plastic media, wheat starch, sodium bicarbonate, carbon dioxide, and ice; non-methylene chloride solvents; thermal/optical paint removal with lasers, Xenon flash lamps; and a combined water and solvent method. Lasers were found to result in

the fastest stripping rate but are still in the experimental stage. The most significant categories of potential damage from these methods are residual stress/cold work-hardening, corrosion, damage of surface treatment, and water intrusion. The use of environmentally hazardous paint removal materials is generally avoided. However, the removed paint waste contains toxic substances which are present regardless of the paint removal method used. Proper worker protection is required for most paint removal methods. The major cost involved in most of these aviation paint stripping methods is the capital cost of purchasing the equipment, but, with increased throughput, the per-aircraft paint removal cost of the equipment decreases. The time efficient removal of paint is a very important factor and is driven by the lost revenue from the downtime of the aircraft.

Conclusions based on the results of this investigation are presented. The potential damage that can be caused by plastic media blasting is of two main types: residual stress and surface flaws. Dense particle contaminant thresholds recommended by user specifications and acceptable in standard practice vary from 0.02 to 0.03 percent. Aggressive use of plastic media blasting (Type II media, 30/40 mesh at 35 psi) can damage alclad surfaces. Strict control and repeatability are required for plastic media blast parameters. Almen strips provide a useful means of monitoring the effects of plastic media blasting. Almen strip tests can not, however, be used as an indicator of surface hardness or surface flaw damage. When plastic media blasting is properly employed and saturation is reached at a safe stress level, the maximum number of strippings that may be performed is unlimited. Alternative paint stripping methods to plastic media blasting currently exist and others are being developed that show potential as viable techniques in terms of aircraft safety, positive environmental impact, and economics.

1. INTRODUCTION

At present there are no industry-wide standards for the use of plastic media blasting as an alternative paint stripping technology. As use of chemical stripping is diminished for economic and/or environmental reasons the need for standards governing the use of plastic media blasting becomes more urgent. The Federal Aviation Administration recognizes the need for uniform alternative blasting application techniques but is apprehensive about the effect of blasting on the material properties of the substrate, especially its fatigue crack propagation rate. The concern is that residual stresses or surface flaws caused by plastic media blasting will increase the fatigue crack growth rate. If there is such an increased growth effect it must be quantified so that a risk evaluation may be performed.

The goal of this project was to investigate the plastic media blasting process and to correlate its effect on the fatigue crack growth properties of 2024-T3 aluminum in 0.032, 0.040, and 0.050 inch thicknesses. Material surface treatments considered were both alclad and anodized for all three thicknesses. The five specific tasks of this investigation were aimed at determining:

a. The underlying cause of any increase in fatigue crack propagation rate due to plastic media blasting.

b. The effect of plastic media particle contamination on blasted surfaces of given material and the recommended contaminant threshold.

c. The control requirements on blasting parameters.

d. The suitability of Almen strip tests for monitoring blasting effects.

e. The maximum number of strippings which can be performed without compromising the metal's fatigue life.

This report describes the attempt to obtain pre-existing data, the test program devised to supplement the pre-existing data, and analytical methods that can be used to study plastic media blessing effects. Also presented are the results of the technical search, the test program (including arc height data, fatigue crack growth data, SEM photography, and surface roughness measurements), and supplementary data obtained in the course of this study. And finally, a comparison is given for the technical, safety, and economic aspects of the other methods being developed to replace chemical paint removal.

1.1. Background

The current primary method of stripping commercial aircraft of paint is chemical stripping. This process is becoming increasingly unacceptable due to its inherent problems. A major liability of the chemical process is that it represents a toxic hazard to those using it to strip the aircraft. The chemical agents used to remove the paint contain substances, such as dichloromethane, which has been identified by the Environmental Protection Agency as a carcinogen and marked for stringent regulatory control. The current chemical process generates large amounts of toxic waste, which presents a hazard to the environment and a high disposal cost to the paint removal company. Also, toxic chemical stripping is damaging to composite substrate and the increasing use of composite materials in aircraft demands an alternate paint removal method.

Many alternatives to chemical paint stripping are being developed and evaluated in the U.S. military and private industry, including blasting with media such as plastic, ice, water, wheat starch, carbon dioxide, and sodium bicarbonate. Of these various paint removal methods, blasting with plastic media is the most readily available technology to replace chemical stripping. It is currently being used by the United States of America's (U.S.) military, some U.S. airlines, and by several members of the European aviation community to remove aircraft coatings. The other paint stripping methods mentioned above are maturing, therefore, they deserve future examination. A general overview of these technologies can be found in Section 5.0.

Before discussing plastic media paint stripping and its effect on thin aluminum substrate, terms used in this report to discuss the process should be defined.

Almen strip - A piece of metal cut to a specified size, usually 0.75 in x 3.0 in, which is used to measure the intensity of a blast.

Almen arc height - A measure of the curve caused by the residual stress imparted by a blast to an Almen strip. It is measured in a specified manner by a dial indicator and is used to quantify the blast intensity.

Blast Pressure - The force per area, measured at the nozzle, used to propel abrasive media at the substrate.

Dwell time - The amount of time that a blast is constantly directed at the same impact point.

Impingement angle - The angle, measured relative to the substrate, at which the blast strikes the surface.

Table 1.1 Definition of Mesh Size by Particle Diameter

U.S. Sieve Size Number	U.S. Sieve Size Dimension (inches)
12	0.066
20	0.033
30	0.023
40	0.017
60	0.010
80	0.007

Reference 6

<u>Media</u> - The material used for paint removal.

<u>Mesh size</u> - The screen size used to define the particle dimensions of the blasting media. See table 1.1.

<u>Strip rate</u> - The amount of coating/paint removed per unit time.

<u>Substrate</u> - The surface to be blasted.

In the United States, the early development of plastic media blasting was marred by several problems which cast doubts on its suitability as a safe aviation process. The first report, Plastic Bead Blast Materials Characterization Study (reference 1) done by Battelle for the Air Force indicated some increases in the fatigue crack propagation rates for aluminum aircraft skin materials. A follow-up report entitled Plastic Bead Blast Materials Characterization Study - Follow-on Effort (reference 2), done by Battelle, traced the problem to dense particle contamination of the blast media. Those dense particles such as sand, with a specific gravity greater than that of the plastic media, caused surface pitting in the aluminum aircraft skin material. This pitting created stress risers that encouraged fatigue crack growth.

The potential for substrate damage from the plastic media paint removal process motivated the establishment of user specifications. The U.S. Air Force, U.S. Navy, Boeing, McDonnell Douglas, and Airbus developed their own specifications, five different ones, for plastic media blasting. These are presented in table 1.2 (reference 14). Concerns, by the Federal Aviation

Administration, over the potential problems with using plastic media to remove paint from civil aircraft structures resulted in Advisory Circular 145.33 (draft stage) (reference 3). The purpose of that document is to provide methods for potential plastic media blasting operators to show compliance with the limited rating for specialized services requirement in Part 145 of the Federal Aviation Regulations (FAR). That Advisory Circular (AC) addresses:

* The training required for plastic media blasting operator qualification.

* The process specifications.

* The quality control process including both inspection and repair of damaged areas.

That draft document identifies the significant factors affecting the successful use of plastic media blasting in civil aviation applications.

The choice of blast parameters is critical to the process. The blast pressure should be minimized consistent with effective paint removal. This limits the kinetic energy imparted to the blasted substrate and provides a margin of safety should a particle contaminant escape the filter process. Strict control over pressure fluctuation is important to prevent surges which could cause substrate damage. The flow rate should be maximized. This increases the paint removal rate and compensates for the low blast pressure. Multiple nozzles or turbine wheels can be used to achieve this aim. The impingement angle should normally be in the range of 30 to 45 degrees. As the angle increases towards the perpendicular, the imparted kinetic energy increases. As the impingement angle gets below 30 degrees, the paint removal rate drops and the potential for plastic flow and erosion of alclad layers increases (reference 4). Contamination of the blast media should be strictly controlled. The ability to recycle used blast media while separating dense particles is very important for practical use of plastic media blasting as an aviation paint removal method.

It should be noted that in manual PMB paint removal systems the use of proper parameters is operator dependent. In a typical hose and nozzle system, the operator must manually maintain the proper blast distance from the substrate, as well as the proper impingement angle with the substrate. The operator must also be conscious of the dwell time so that no one substrate location is subjected to the blast longer than necessary for paint removal. Excessive dwell time can increase the residual stress imparted to the substrate. Operator training and job performance standards are important factors in the successful manual use of plastic media blasting in aviation paint removal.

In order to establish and examine the correlation between the

blast parameters used and the potential substrate damage, the intensity of the blast must be quantified. The method commonly used by industry is the Almen strip test which was originally developed to measure the intensity of shot-peening operations. A piece of substrate material, cut to a standard size, is clamped in a holding frame by four bolts and then blasted. The substrate material, known as an Almen strip, is then removed from the holding frame. The residual stresses imparted by the blast cause the Almen strip to become convex on the blasted side. The arc height of this curvature is measured with a specified dial gauge indicator.

Almen strips are used to ensure that the residual stress induced in the substrate does not exceed the level at which it would increase the fatigue crack propagation rate. The arc heights measured from each Almen strip after each blast cycle can be used to plot a curve of arc height versus blast cycle. This produces a saturation curve that becomes asymptotic as it approaches the saturation stress level for that substrate. Saturation should be below a level that will not cause increased fatigue crack propagation rates. Then, for any additional blast cycles using the same parameters, no further significant residual stress will be caused in the substrate by the blast.

TABLE 1.2 A COMPARISON OF PMB PROCESS SPECIFICATIONS ON AIRFRAMES

(Courtesy Pauli & Griffin Company (Reference 14))

	US AIR FORCE	US NAVY	BOEING	BOEING	DOUGLAS	AIRBUS
	T.O. 1-1-8	PMB SPEC	D6-54705	D6-55564	CSD #4	SIL 51-007
	1989 Sep 1	REV A	1988 Nov 14	1991 Jan 11	1988 Oct 19	1989 Sep 6
	CHANGE 6	1991 Jun 19				AIPS 02-100
	1991 Sep 30					1990 Jan 30
APPLICABILITY	All aircraft	All Aluminum	2024-T3 Clad Al		DC-8, DC-9, C-9	A-300, A-310
	Alclad Al	Airframes and	7075-T6 Clad Al		MD-80, DC-10,	A-300-600
	Nonclad Al	Components +	Steel		KC-10A	A-320
	Composites	Steel & Ti	Titanium		Alclad Al	All metals
	Steel				Anodized Al	All composites
	Titanium				Steel	no fiber reinforced
	Magnesium				Titanium	parts coated with
	Copper Alloy					aluminum foil or
	Depot & Field					plastic
RESTRICTIONS						
• NO OF PMB CYCLES	No limit	No limit	One	No limit	Four	No limit
• MIN THICK AL	See below	0.016 in	0.036 in		0.050 in	1.2 mm (0.047")
• MIN THICK STEEL/TI	See below	None	No min		0.050 in	No min
• MIN THICK-ALL METALS						
TYPE I MEDIA	0.016 in					
TYPE V MEDIA	0.016 in					
TYPE II MEDIA	0.032 in					
• ANODIZED PARTS OK PMB	Yes	Yes	No		Yes	Yes
• REPLATE PARTS?	Not specified	Not specified	Yes		Yes	Not specified
• COMPOSITES OK?	Yes, recommended	No	No	Yes, strip	No	Yes
	whenever possible			to primer		
• LEAVE BASIC PRIMER?	Metal- not specified	Optional	Not specified		Not specified	Yes
	composite-"flag"					
•LEAVE ANTI-STATIC						
PAINT OR TEDLAR FOIL	Not specified	Not specified	Not specified		Not specified	Yes
FAA APPROVAL	NA	NA	Yes		Yes	No
MEDIA AUTHORIZED	Types I & V	Type V	Types I, II, V	No restriction	No restriction	Type II, Grade A
(TYPES PER	Type II (if Type I					40-60 & 60-80
MIL-P-85891A,	cannot strip 0.5					(Certified)
1992 APRIL 1)	sq ft/min)-Caution					
	for damage					

TABLE 1.2 A COMPARISON OF PMB PROCESS SPECIFICATIONS ON AIRFRAMES (CONT.)

	US AIR FORCE	US NAVY	BOEING	BOEING	DOUGLAS	AIRBUS
MEDIA SIZE	20-40 mesh new					
	12-16 make-up					
MEDIA NOT AUTH'IZED	Types III & IV					
MAXIMUM MEDIA						
CONTAMINATION LEVEL					No max	No specified
• TWO-STEP METHOD					level operator	
HIGH DENSITY (>1.991)	0.02% (200 PPM)				must have DPS	
OVERALL (>1.575)	2% (20,000 PPM)				capability	
• ONE-STEP METHOD		0.02% (200 PPM)	0.03% (300 PPM)			
• FREQUENCY OF TESTING	Longer of 80 hr	maintain media	maintain media			
	of equipment	less than 0.02%	less than 0.03%			
	operation or each	DPS required in				
	aircraft	reclaim system				
PMB PARAMETERS ON						
METALLIC SURFACES					No specified	
					parameters.	
NOZZLE DESIGN		1/2"			See operators +	Straight Bore
					blast parameter	
NOZZLE LENGTH					qualification	
					test procedure	
NOZZLE THROAT SIZES			3/8 & 1/2 in		below	8 & 16 mm
			(10 &13 mm)			(5/16 & 5/8 in)
MEDIA FLOW RATE						Not specified
• 3/8 IN NOZZLE		Capable of 800	400-450 lb/hr			
• 1/2 IN NOZZLE		pph. 450-550 pph	700-800 lb/hr			
		operational				
NOZZLE PRESSURE			30 +/- 5 psi			1.5 bar (22 psi) max
• TYPE I MEDIA	40-60 psi					
• TYPE II MEDIA	20-30 psi					
• TYPE V MEDIA	25-40 psi	30 psi max				
NOZZLE DISTANCE						150 mm (6 in)
• TYPE I MEDIA	12-24 in					

TABLE 1.2 A COMPARISON OF PMB PROCESS SPECIFICATIONS ON AIRFRAMES (CONT.)

	US AIR FORCE	US NAVY	BOEING	BOEING	DOUGLAS	AIRBUS
NOZZLE DISTANCE (Cont.)						
• TYPE II MEDIA	18-30 in					
• TYPE V MEDIA	12-24 in	24 in				
• 3/8 IN NOZZLE			14-18 in			
• 1/2 IN NOZZLE			14-48 in			
NOZZLE ANGLE			30-85 degrees			30-45 degrees
• TYPE I MEDIA	30-90 degrees					
• TYPE II MEDIA & V MEDIA	0-60 degrees					
• TYPE V MEDIA-clad + comp	0-60 degrees					
• TYPE V MEDIA-nonclad	30-90 degrees					
MAX ROUGHNESS (uin)			Ra = 350 u-in	Ra = 350 u-in		Ra = 276 u-in
				Clad		
MAX ROUGHNESS,			Ra = 9 um	Ra = 9 um		Ra = 7 um
(MICRONS)						
PMB PARAMETERS ON						
COMPOSITES						Same as Al
NOZZLE PRESSURE						
• TYPE I MEDIA	30-60 psi					
• TYPE II & V MEDIA	25-40 psi					
NOZZLE DISTANCE	12-24 in					Same as Al
NOZZLE ANGLE	45-90 degrees					Same as Al
CAUTIONARY	Use primer as a flag					
COMMENTS						
MAX ROUGHNESS						Same as Al
GENERAL NOTES	Particles finer than 80					Total removal of
	mesh are not					TC & P is ok on
	damaging.					fastener heads
PLASTIC MEDIA						
REPLENISHMENT	12-16 mesh					Must use same
						manufacturing
						batch (size &
						grade)

TABLE 1.2 A COMPARISON OF PMB PROCESS SPECIFICATIONS ON AIRFRAMES (CONT.)

	US AIR FORCE	US NAVY	BOEING	BOEING	DOUGLAS	AIRBUS
OPERATOR TRAINING & QUALIFICATION REQ'D?	Yes * Thoroughly trained & thoroughly indoctrinated	Yes, most stringent interpretation plus reqm't for recertification	Yes * Formal training * Practical trng * apprenticeship * 9 reqmts for course content		Yes * Must requalify on a regular basis	Yes * Certified operators and approved training
OPERATOR & BLAST PARAMETER QUALIFICATION TEST PROCEDURE						
OPERATOR QUALIFICATION	Yes, see Operator Training & Qualification above	Yes, see Operator Training & Qualification above	Yes,see Operator Training & Qualification above		Yes, see this section	Yes, see this section
PROCESS QUALIFICATION	No	No	No		Yes, see this section	Yes, see this section
* ALUMINUM TEST PROCEDURES						
** ALMEN TEST STRIP MANUFACTURE						
NUMBER OF STRIPS PER OPERATOR & PROCESS					1	5
ALUMINUM ALLOY					2024-T3 nonclad	clad 7075
LENGTH X WIDTH, IN					3.00 x 0.75 in	3.93 x 11.8 in
LENGTH X WIDTH, MM					76.2 x 19.1 mm	100 x 300 mm
THICKNESS, IN					0.032 in	0.047 in
THICKNESS, MM					0.81 mm	1.2 mm
* ALMEN STRIP PREPARATION						
MANUFACTURER PAINT SYSTEM					Conversion ctg epoxy primer PU topcoat air dry,oven cure	Chrmic acid anodz base primer, wash primer, PU primer &topcoat,oven cure
* MAX ARC HEIGHT ALLOWED, IN				0.008 in	0.008 in	0.008 in
MAX ARC HEIGHT ALLOWED, MM				0.15 mm	0.15 mm	0.15 mm
* MAX SURFACE ROUGHNESS ALLOWED			Clad, Ra = 350 u-in			Ra = 7 microns
* FURTHER PROCESSING OF FIRST TEST STRIP						* degrease * recoat wp + p + tc * adhesion test * 2 addn'l cycles strip & paint total 3 cycles

TABLE 1.2 A COMPARISON OF PMB PROCESS SPECIFICATIONS ON AIRFRAMES (CONT.)

	US AIR FORCE	US NAVY	BOEING	BOEING	DOUGLAS	AIRBUS
*SECOND AL TEST STRIP PROCEDURE?						Yes, w/clad 2024
						same as above
* FATIGUE LIFE TESTING				* No reduction after 5 cycle test		
* CRACK GROWTH TEST				TBD		
* CRACK DETECTABILITY TEST				TBD		
* TAPE ADHESION TEST				Yes		
* MEDIA SANDWICH CORROSION				Yes		
* CLAD PENETRATION TEST				Yes		
* RESIDUAL STRESS TEST				Yes		
COMPOSITE TEST PROCEDURES						
* COMPOSITE TEST PANELS						
NUMBER OF PANELS PER OPERATOR & PROCESS						5
PANEL SIZE						150 X 150 mm
						(6 X 6 in)
MATERIAL 1						Carbon/Epoxy
CONSTRUCTION 1						6 ply
MATERIAL 2						Aramid/Epoxy
CONSTRUCTION 2						6 ply
MATERIAL 3						Aramid/Epoxy
CONSTRUCTION 3						H'comb, 2 ply/side
MAX ROUGHNESS ALLOWED						Same as Al
NON-DESTRUCTIVE TESTS						
CARBON/EPOXY						Ultrasonic
ARAMID/EPOXY						Tap test

TABLE 1.2 A COMPARISON OF PMB PROCESS SPECIFICATIONS ON AIRFRAMES (CONT.)

	US AIR FORCE	US NAVY	BOEING	BOEING	DOUGLAS	AIRBUS
FURTHER PROCESSING						* Similar to Al
						total 3 cycles
* VISIBLE FIBER DAMAGE, 10X MAGNIFIER				None		
* DELAMINATION				None		
* LONG BEAM FLEXURE VALUE				No decrease		
* OTHER NDI				As needed		
* TAPE ADHESION TEST				Yes		
* MEDIA SANDWICH CORROSION TEST				Yes		
QUALIFYING NEW MEDIA						
DOES THE PROCESS	No	No	No	Yes,because	Yes,because	Yes, section 3-3-7
SPEC INCLUDE PROCEDU-				qualification	qualification	describes fatigue
RE FOR QUALIFYING MEDIA				test proce-	test proce-	testing required for
TYPES OTHER THAN THOSE				dure allows	dure allows	qualification of new
SPECIFIED?				operator to	operator to	media
				select media	select media	

2. TECHNICAL APPROACH

This project was an investigation into the effects of plastic media blasting (PMB) on the fatigue crack growth rate in thin aluminum aircraft skins. The approach used was a two phase effort that combined a technical search with a test program.

2.1 TECHNICAL SEARCH

The main purpose of this search was to determine what fatigue crack propagation testing results had previously been obtained with plastic media blasting of 2024-T3 aluminum in the thicknesses and surface treatments being investigated. The technical literature obtained was assessed for:

* Containing data specific to the aluminum alloy, surface treatments, and material thicknesses being investigated by this study.

* Containing specific information regarding the five tasks of this study.

* Containing information regarding alternative paint stripping methods.

In the course of obtaining reports, papers, and related literature, it was discovered that much of the testing that had been performed was for 7075-T6 aluminum, a commonly used alloy for military aircraft. Much of this information was not directly applicable to the materials being studied by this project. The technical search revealed the nature of the plastic media blasting process, the established testing practices, and current industry standards on blasting parameters. Section 3.1 summarizes the contributions made by the survey sources to the study of plastic media blasting and its effect on thin 2024-T3 aluminum.

2.2 TEST PROGRAM

To supplement the technical survey results a test program was also conducted. The safe use of plastic media blasting in aviation paint removal is dependent on the combination of parameters applied to the blasted substrate. The approach used for this test program was to narrow the range of parameters to be tested to those determined to be most influential to the process effect. Table 2.1 summarizes the blast parameters used in this test program. Each of the plastic media blasting users listed in figure 1.2 have developed their own set of operating procedures based on

Table 2.1 Blast Parameter Specifications

BLAST PARAMETER	SPECIFIED VALUE
Media Type	Type II, Size 30/40
Nozzle Pressure	35 psi
Distance	12 inches
Nozzle Diameter	0.5 inch
Media Flow rate	870 lb/hr
Impingement Angle	90 degrees
Number of Blast Cycles	4 (1 initial
	stripping, then 3
	subsequent blasting)

their own proprietary analyses. In general, the three key factors found to determine a safe plastic media blasting process were (1) low dense particle contamination, (2) low pressure, and (3) high flow rate.

Media type was found to be extremely important in past tests, particle size and hardness being related to strip rate and surface roughness. Figure 1.0 describes mesh size in terms of particle dimensions. The mesh size chosen, 30/40, is an intermediate particle size that has good paint stripping qualities (reference 6). The contamination level has been found, by Battelle's Air Force studies in particular, to be very influential in causing substrate damage. The contamination level level chosen for this test was 0.05 percent. An aggressive media, Type II, was used in an intermediate particle size, 30/40, at a maximum allowable contamination of 0.05 percent.

The selected test parameters, based on the technical research, are summarized in table 2.1. The nozzle pressure, media flow rate, and angle of impingement are the blasting parameters that have the greatest effect on the substrate. The values selected; for these three parameters are 35 psi, 870 lb/hr, and 90 degrees. A blast distance of 12 inches was a conservative distance (reference 5); there are two common sizes of nozzle diameter used by the American dry stripping community, 1/2 and 3/8 inch.

The pressure, flow rate, and angle of impingement are the blasting parameters that have the greatest effect on the substrate. The pressure chosen was 35 psi which is the conservative value used by industry with Type II media (reference table 1.2). An impingement angle of 90 degrees was chosen because it is the most potentially damaging angle due to full application of the particles' kinetic energy. A flow rate of 870 lb/hr was chosen from that used in a

recent SAE paper written by Battelle and DuPont (reference 7). The number of blasting was chosen to be four because this would provide enough data points to construct a saturation curve to indicate trends in the process effect. Table 2.1 summarizes these parameters chosen from the technical search.

When parameters are controlled for repeatability, the residual stresses imparted by the blast become asymptotic at a stress saturation point. This fact means that for test purposes the number of blastings needed are those required to construct a saturation curve. The paint was applied to the appropriate aluminum sample and artificially aged according to McDonnell Douglas requirements CSD #4 (reference 8) and then it was stripped. The stripped metal was then blasted 3 more times. This was necessary due to experimental time constraints involved with repeatedly aging the paint and was considered to be a more severe, conservative test of the process since the blast effect was not reduced by the paint coating. See Appendix B for documentation of the painting and blasting process, including the specific paint application and aging process used.

The substrate tested were 2024-T3 aluminum, in both the alclad and anodized condition, for the thicknesses of 0.032, 0.040, and 0.050 inches respectively. The measurements taken during the blasting test process were the stripping rate, the dwell time, and the media breakdown rate.

The testing addressed the aforementioned material thickness and surface treatments for thin aluminum skins because of these materials' common usage in aircraft. The blasting parameters chosen represent a combination of those currently specified by industry. It was the purpose of this program to conservatively test what was determined to be the most influential combination of parameters for the plastic media blasting process.

A fatigue crack propagation test program was also performed to assess the effect of plastic media blasting on the 2024-T3 aluminum specimens. The test matrix specified for this program is described in table 2.2. The detailed specifications for these tests, including photographs of the test equipment, are presented in Appendix D. The results are presented and discussed in section 4.3.

Table 2.2 Fatigue Crack Propagation Test Matrix

MATERIAL THICKNESS	ANODIZED SPECIMEN As Received	ANODIZED SPECIMEN PMB Treated	ALCLAD SPECIMEN As Received	ALCLAD SPECIMEN PMB Treated
0.032"	1	2	1	2
0.040"	1	2	1	2
0.050"	1	2	1	2

TOTAL = 18 specimens

3. RESULTS AND DISCUSSION

This section discusses the results of the technical search and the test program performed for this investigation. The highlights of the technical search, including an analytical method relating arc height with residual stress values, are presented in this section. The full range of related sources that were identified in this report are presented in Appendix A and are intended to aid future researchers. Test results presented include Almen strip arc heights, fatigue crack propagation rates for baseline and blasted specimens, Scanning Electron Microscope (SEM) photographs, surface roughness measurements, and supplementary Almen arc height data supplied by Messerschmitt-Bolkow-Blohm (MBB).

3.1 TECHNICAL SEARCH RESULTS

The first part of this project was, as previously stated, to conduct a technical liter· search. The results of this search have been organized into t… e main categories:

- Technical Reports and Papers
- Industry Specifications
- Analytical Method

The search results presented in this section were chosen because they provided information that was significant to at least one of the three evaluation criteria listed in section 3.1.

3.1.1 Technical Reports and Papers

There were several primary sponsors of PMB research identified in aviation applications as a paint removal process. The U.S. Air Force was one of the first organizations in the United States that studied the process and its effects on the material and fatigue properties of aluminum aircraft skin. DuPont and MBB have also performed significant research on plastic media blasting. An overview of some of the more important technical literature from these three sponsors is presented.

Those reports sponsored by the U.S. Air Force are summarized in table 3.1. In these U.S. Air Force studies, 2024-T3 aluminum was tested in the bare condition. The bare aluminum is frequently tested because it has no surface coating to absorb the blast and therefore provides a conservative test of the blast effects. The data were therefore not directly related to the specific materials being investigated by this effort. Several useful results were found in these reports, however, and these are:

- Dense particle contamination caused surface flaws that seemed to provide the primary mechanism for reducing fatigue life.
- Use of virgin blast media eliminated fatigue loss.
- Thicker and alclad materials showed less fatigue life reduction than thinner and nonclad materials.

The cushioning effect observed in clad substrate and the effect of surface flaws are shown in the arc height, surface roughness measurements, and SEM photographs presented later in this report.

The reports sponsored by DuPont are summarized in table 3.2. Again, as in the U.S. Air Force studies, bare 2024-T3 aluminum was studied. The significant results from these reports are:

- Plastic blast media was categorized according to media aggressiveness and paint stripping effectiveness.
- Use of saturation curves was emphasized to present Almen arc height data.

The use of Type II media in this study was partly influenced by its characterization as being very aggressive to the substrate yet effective as a paint stripper. The Almen arc height data are presented in sections 3.2 and 3.6 in saturation plots.

Table 3.1 Batelle Studies - Air Force

Source	Materials Tested/Blast Parameters Specified	Findings/Conclusions
BATTELLE-AIR FORCE Jul-86 PMB-I	• 7075-T6 bare & alclad • 2024-T3 bare (0.016" TO 0.190") • 2024-T81 bare (0.080") • 2219-T81 bare (0.063") • 7475-T761 alclad (0.071") • 6A1-4V Titanium (0.063") • Type II media, size 30/40.	• Thicker and alclad materials showed less fatigue life reduction. • Simulated blast cycles had similar results to actual blast cycles. • 0.016" & 0.032" thicknesses showed up to 98 % fatigue life loss and increased crack growth rate after 4 blast cycles. • Surface damage seemed to be primary mechanism for reducing fatigue life.
BATTELLE-AIR FORCE Mar-87 PMB SEPARATOR STUDY	• Investigation into methods of heavy particle contaminant separation.	• Use separation screens to exclude particles that are too large. • Use air-driven cyclone for particles that are too small. • Use magnetic separators for ferrous particles. • Use eddy current devices for non-ferrous, conductive particles. • To remove sand, use either a fluidized bed, electrostatic, or hydrocyclone separator.
BATTELLE-AIR FORCE Nov-87 PMB-II	0.016" & 0.032" • 7075-T6 bare • 7075-T6 alclad • 7075-T6 anodized • 2024-T3 bare	• Blast angle, distance, pressure had little effect on arc height. • Type I media showed potential for reducing residual stresses. • Use of virgin media eliminated fatigue life loss.
BATTELLE-AIR FORCE Oct-89 PMB CONTAMINANT EVALUATION	• 7075-T6 0.032" • Contaminants evaluated were paint, aluminum, magnesium, sand, & high density plastic. • Contamination levels = 0.002, 0.020, & 0.200 %	• Only sand and high density cause damage, sand being more severe. • Sand at just 0.002% caused surface flaws.
BATTELLE-AIR FORCE May-90 DATABASE ENHANCEMENT STUDY	• 2024-T3 (0.032",0.063") • Type I media @ 12", 18"; 60 PSI, 30 & 60 degrees, 1 & 4 blastings, 3/8" nozzle. Type II media @ 12", 60 psi, 60 degrees, 4 blastings, and 3/8" nozzle.	• No significant decrease in fatigue crack growth resistance from PMB. • PMB actually reduced the crack growth rate.

Table 3.2 Batelle Studies - DuPont

Source	Materials Tested/Blast Parameters Specified	Findings/Conclusions
BATTELLE-DuPONT Jan-90 PMB THIN SENSITIVE SUBSTRATE	• 2024-T3 (0.016")	• Efficient blast parameters for 2024-T3 0.016" determined to be: 45 degree impingement, 30 PSI, 0.5" nozzle, 12" distance, 600 lb/hr using 30/40 Type L(DuPont).
BATTELLE-DuPONT Jan-89 PMB-COMPARATIVE STUDY	• Comparison of media types I, II, III, VL & Vx 0.032" • 7075-T6 bare & clad • 2024-T3 bare	• Type II has best strip rate, is most aggressive. • Type I has poorest strip rate. • Types VL &Vx are intermediate in stripping effectiveness and aggressiveness.
BATTELLE-DuPONT Jun-89 PMB-FOLLOW -UP STUDY	• Mesh size was varied from 12/16 to 40/60 for type L media (VL) • 2024-T3 bare (0.032")	• Larger mesh sizes had lower initial arc heights, higher strip rates, and larger saturation arc heights.
DuPONT 1990 PMB-TECHNICAL GUIDE	• Summary of PMB information.	• Type VL & Vx good compromise between strip rate and low aggressiveness. • Saturation curves should be used to evaluate substrate damage.

Table 3.3 summarizes the results of two reports generated by Messerschmitt-Bolkow-Blohm (MBB). These, like the Du Pont reports, primarily focused study of 2024-T3 aluminum in the bare condition. The significant results from these reports are as follows:

- Surface roughness effects on the fatigue crack growth rate were offset by the crack retardation effects of the residual compressive stress induced by the blast.
- No significant differences were found between the effects of plastic media blasting on bare and anodized aluminum.

Table 3.3 Messerschmitt - Bolkow - Blohm

Source	Materials Tested/Blast Parameters Specified	Findings/Conclusions
MBB LABORATORY REPORTS 1986-88 PMB & CRACK PROPAGATION RATE	• 2024-T3 clad & bare (0.063") • Media: Type II (assumed from usual practice), nozzle: 0.39", flowrate: 0.088 ft^3/sec., pressure:44 & 51 psi, angle:15 & 30 degrees, distance: 10".	• Effect of increased surface roughness on crack growth rate offset by induced compressive stresses. • No significant differences between clad and unclad materials.
SCHLICK/MBB REPORTS Oct-89 PMB FOR CANADIAN F-18 MATERIALS	• 7075-T6 alclad (0.012") • Sandwich and monolithic laminate • Media: Type II, size 30/40, nozzle: 0.55", distance: 12", angle: 30 degrees, pressure: 29 psi, 4 strippings.	• Surface effects considered small. • Less than 15% change in compressive strength.

3.1.2 Industry Specifications

Several organizations concerned with the use of plastic media blasting in aviation paint removal applications have established user specifications. The U.S. Air Force, based primarily on its own research into the plastic media blasting process, has developed a set of specifications that define the acceptable range for operational factors that include blast parameters, contamination levels, and substrate thicknesses.

Table 3.4 Industry Plastic Media Blasting Specifications

	USAF	BOEING	DOUGLAS	AIRBUS
No. of PMB Cycles	No Limit	One, for now	Four	No Limit
Min. Al Thickness	Type I: 0.016 in. Type II & V:0.032in.	0.036 in.	0.050 in.	1.2 mm (0.047 in.)
Plastic Media Type	Type I, II & V	Type I, II & V 20/30 or finer	No Restriction	Type II, Grade A 40/60 & 60/80
Contamination	High Density (>1.991): 0.02% Overall (>1.675): 2%	0.03%	0.03% DPS Capability	
Nozzle Diameter		3/8 & 1/2 in.		8 & 16 mm (5/16 & 5/8 in.)
Flow Rate		3/8 in:400-450lb/hr 1/2 in:700-800lb/hr		
Nozzle Pressure	Type I:40-60 psi Type II&V:20-30 psi	30±5 psi		1.5 Bar (22 psi)
Nozzle Distance	Type I: 12-24 in. Type II&V: 18-30 in.	3/8 in.: 14-18 in. 1/2 in.: 14-48 in.		150 mm (6 in.)
Nozzle Angle	Type I: 30°-90° Type II&V:0°-80°	30°-85°		30°-45°
Max. Arc Height			0.006 in.	0.15 mm (0.006 in.)
Max. Surface Roughness		Ra 350 μ in.		Ra 7 micron (Ra 276 μ in.)

Note: DPS= Dense Particle Separator

Major airframe manufacturers such as Boeing, McDonnell Douglas, and Airbus, because of concern with the effect of blast paint stripping methods on their aircraft's airworthiness, have also established user specifications for plastic media blasting.

The specifications of the U.S. Air Force and airframe manufacturers are summarized in table 3.4. Full documentation of these specifications are contained in references 8, 9, 10 , and 11.

From table 3.4, it can be seen that:

- The acceptable level of dense particle contamination has been defined.
- Two specifications use the Almen strip as a measure to limit the amount of energy transferred to the substrate.
- A maximum allowable Almen arc height is specified for users of the blast process.
- The maximum allowable number of strippings has been defined and is specified as unlimited by the U.S. Air Force and Airbus, subject to the rest of their specifications.

These process specifications all present answers to many of the questicns being investigated by this project.

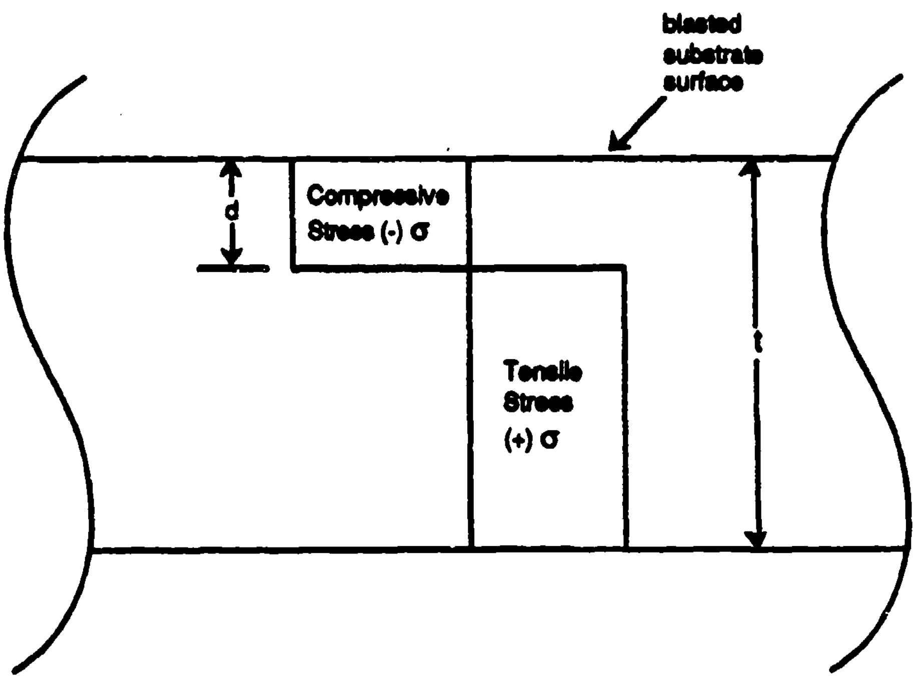


Figure 3.1 Stress Configuration of Constrained Almen Strip

3.1.3 Analytical Methods

In investigating the plastic media blasting parameters it became apparent that an analytical method that related the Almen strip arc height with the induced residual stress would be very useful. Because the potential combination of blasting parameters is enormous, a way was sought to determine the blast effect on the crack growth without testing every parameter combination. Through the technical survey a

method was found that had been developed in a U.S. Air Force report entitled Plastic Media Blasting Engineering Project 8TS0845 (reference 12). The following analysis is taken from that report.

For a constrained specimen that has been blasted (example: Almen strip being held in a grip) the stress distribution will be that which is shown in figure 3.1. The compressive stress is the residual stress induced by the PMB on the blasted surface. The tensile stress acts in opposition to the induced compressive stress.

A force balance based on figure 3.1, assuming a uniform distribution for both tensile and compressive stresses (σ_c), results in the following equation:

$$\sigma_c = \frac{\sigma_t(t-d)}{d} \qquad \text{(Equation 1)}$$

where t = the thickness of blasted substrate, d = the depth of compressive stress layer, and σ_t = the back side tensile stress.

It can be shown that the depth of the compressive stress can be expressed by the following equation (for derivation of this expression refer to reference 12):

$$d = \frac{(\sigma_{t1}t_1 - \sigma_{t2}t_2)}{(\sigma_{t1} - \sigma_{t2})} \qquad \text{(Equation 2)}$$

where σ_{t1}, σ_{t2} = the back side tensile stresses in two specimens of different thickness, and t_1, t_2 = the two thicknesses of the blasted specimens.

The back side tensile stress in a specimen can be expressed as:

$$\sigma_t = \sigma_a + \sigma_b \qquad \text{(Equation 3)}$$

where $\sigma_a = E\varepsilon$ the "blast-strain" stress on the back surface, and

$\sigma_b = \frac{My}{I}$ the outer surface bending stress caused by constraining the substrate. Equation 3 can also be shown as:

$$\sigma_t = E\varepsilon + \frac{My}{I} \qquad \text{(Equation 4)}$$

where,

E = Young Modulus of the substrate,
ε = back surface strain of Almen strip,
y = distance from neutral axis of Almen strip to outermost surface (assumed to be t/2), and

$$M = \text{Fuch's Equation} = \frac{8EIh}{c^2} \qquad \text{(Equation 5)}$$

where c is shown in figure 3.2.

By obtaining strain gage readings on two substrate thicknesses of the same material subjected to the same blast process, the tensile stresses may be calculated using equation 4 and then used to determine the depth of the compressive stress layer with equation 2. Knowing the value of d, the depth of the compressive stress, one can calculate the value of the compressive stress using equation 1.

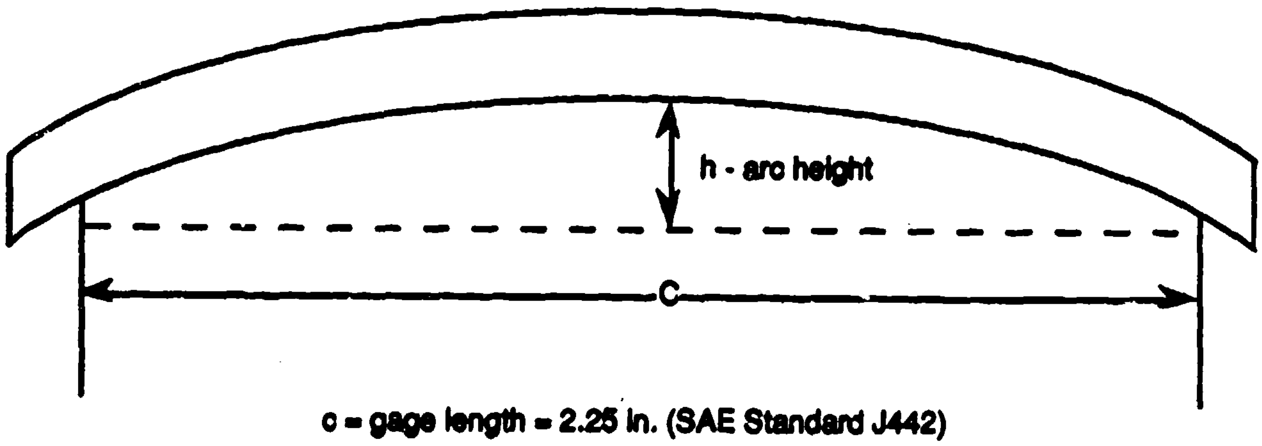


Figure 3.2 Almen Strip Measurements Used for Stress Determination

This surface compressive stress can act to retard crack growth; however, the backside tensile stress acts to increase the crack growth rate. The backside tensile stress induced by the blast must not exceed a value that would significantly increase the crack growth rate of the material. If one knows the value of the residual compressive stress imposed by the blast process, then a new stress ratio and a new crack growth rate may be calculated. This method utilizes Almen strips

to determine the blast-induced compressive stress levels and how they affect the crack propagation rate.

The stress ratio is defined as:

$$R = \frac{\sigma_{min}}{\sigma_{max}} \qquad \text{(Equation 6)}$$

where σ_{min} = the minimum value of cyclic stress and

σ_{max} = the maximum value of cyclic stress

The stress ratio adjusted for the residual stress induced by plastic media blasting is defined as:

$$R_{adj} = \frac{\sigma_{min} + \sigma_{res}}{\sigma_{max} + \sigma_{res}} ; \sigma_{res} = \sigma_t + \sigma_b \qquad \text{(Equation 7)}$$

where _res is the residual stress composed of the backside tensile stress and the bending stress caused by constraining the specimen.

The new crack growth rate may then be determined using the adjusted stress ratio in the Walker equation:

$$\frac{d_a}{d_n} = C(1 - R_{adj})^n K^P \qquad \text{(Equation 8)}$$

where *C*, *n*, and *P* = Walker Coefficients and *K* = stress intensity.

Table 3.5 Almen Strip Test Result Summary - Average Arc Heights

Blast Cycle	Anodized, Thickness (inches)			Alclad, Thickness (inches)		
	0.032	0.040	0.050	0.032	0.040	0.050
1	11.2	3.8	3.8	5.2	3.2	0.6
2	13	4.2	4.2	7.8	4	0.8
3	15.2	4.6	4.2	8.4	4.4	1.2
4	16.4	5.4	4.8	9	5	1.2

Note: Arc heights given in thousandths of an inch.

3.2 ALMEN STRIP TEST RESULTS

Almen strip tests were performed to measure the blast effects of intensity. The blast parameters chosen for a given test directly influence the blast intensity and the Almen arc height. The blast parameters used for these tests are presented in table 2.1. Five Almen strip tests were performed for each of the three thicknesses and two surface treatments, for a total of 30 Almen strips. The average arc heights are listed for both the anodized and alclad specimens relative to the blast cycle in table 3.5.

Plots of arc height versus blast cycle are known as saturation curves. These curves provide useful presentations of Almen arc height data because they illustrate whether the blast-induced residual stress is becoming asymptotic at a specific level. Saturation curves also facilitate comparison of the effect of the same blast intensity on different test specimens. The Almen arc heights for this test program were plotted in saturation curves and will now be discussed.

The arc heights were found to vary inversely with material thickness. In figure 3.3 the average arc height saturation values for anodized aluminum can be seen to increase as the material thickness decreases. In figure 3.4 the same trend can be more clearly seen for alclad aluminum. It is reasonable to expect that thinner specimens will be more significantly affected when subjected to the same blast intensity. For the same blast intensity the induced value and depth of the compressive stress layer will be the same regardless of substrate thickness. The thinner specimens, however, will have higher values of backside tensile stress than thicker specimens. This is

significant because this backside tensile stress promotes increased crack growth rates.

The arc heights were also found to vary with surface treatment with those for anodized aluminum being consistently higher than those for alclad aluminum in all thicknesses. A comparison of the average arc height saturation curves for 0.032 inch anodized and 0.032 inch alclad is shown in figure 3.5. This plot shows that the anodized specimens had a larger warp (arc) than the alclad specimens. This same trend is demonstrated in figure 3.6 for 0.040 inch aluminum and in figure 3.7 for 0.050 inch aluminum. This difference can be attributed to the absence of a cushioning alclad layer in the anodized aluminum, exposing them more to the blast. Additionally, the average dwell time for the anodized materials was 0.34 sec/ft^2 and while that for alclad materials was 0.56 sec/ft^2. This demonstrates that despite being exposed for a shorter time the anodized materials had a greater plastic deformation than the alclad materials when exposed to the same blast intensity.

One observation that should be made is that the Almen strip tests indicate the effect of blast intensity on the substrate but do not indicate any surface damage effects. In the early research performed into plastic media blasting effects, discussed in section 3.1.1, surface flaws were found to affect the fatigue crack propagation rate. Surface roughness measurements and Scanning Electron Microscope (SEM) photography may be used to assess and measure the surface damage caused by the plastic media blasting operation. Results of such tests are presented in sections 3.4 and 3.5, respectively.

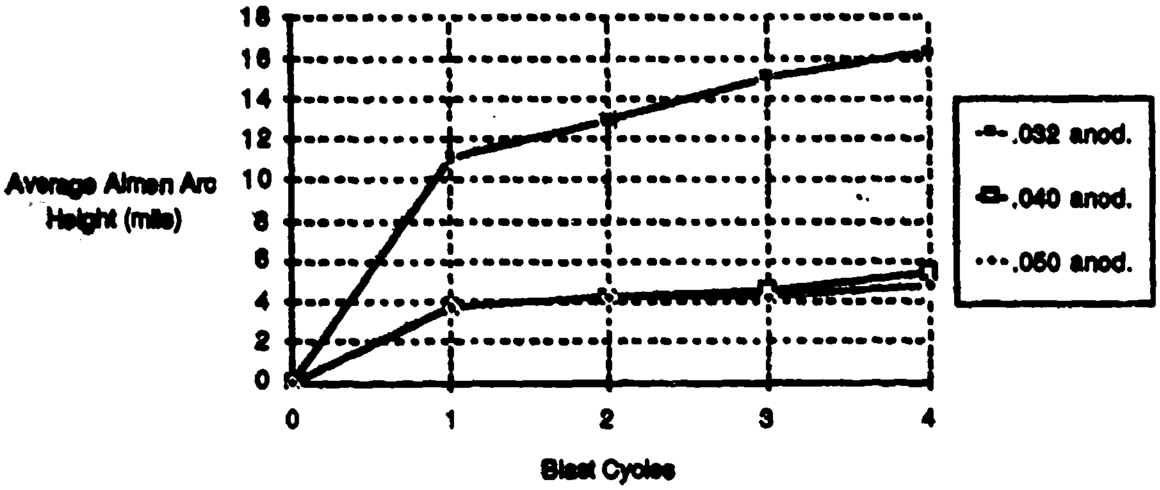


Figure 3.3 Average Almen Strip Arc Heights - 2024-T3 Anodized Aluminum, 0.032, 0.040, & 0.050 inch Thicknesses

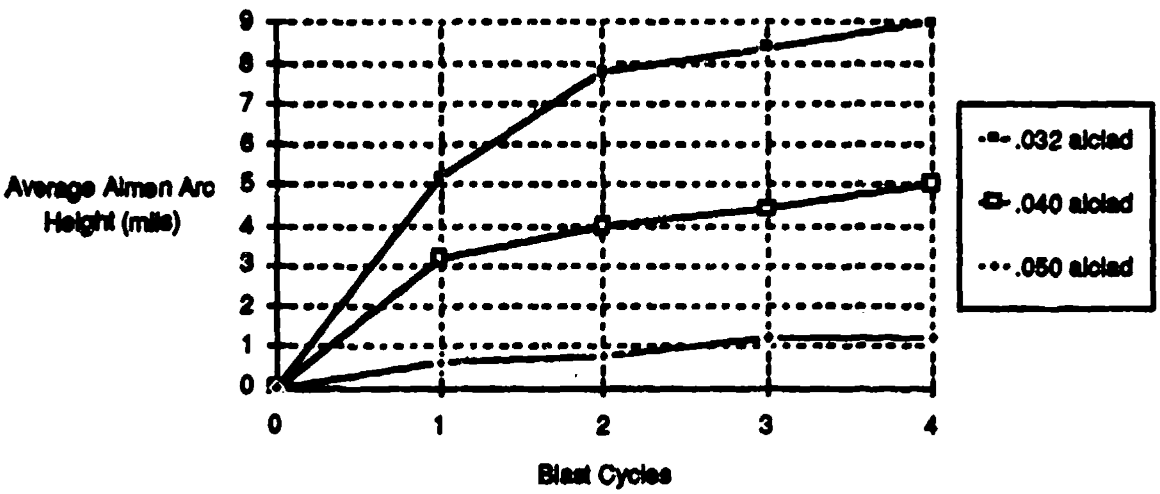


Figure 3.4 Average Almen Strip Arc Heights - 2024-T3 Alclad Aluminum, 0.032, 0.040, & 0.050 inch Thicknesses

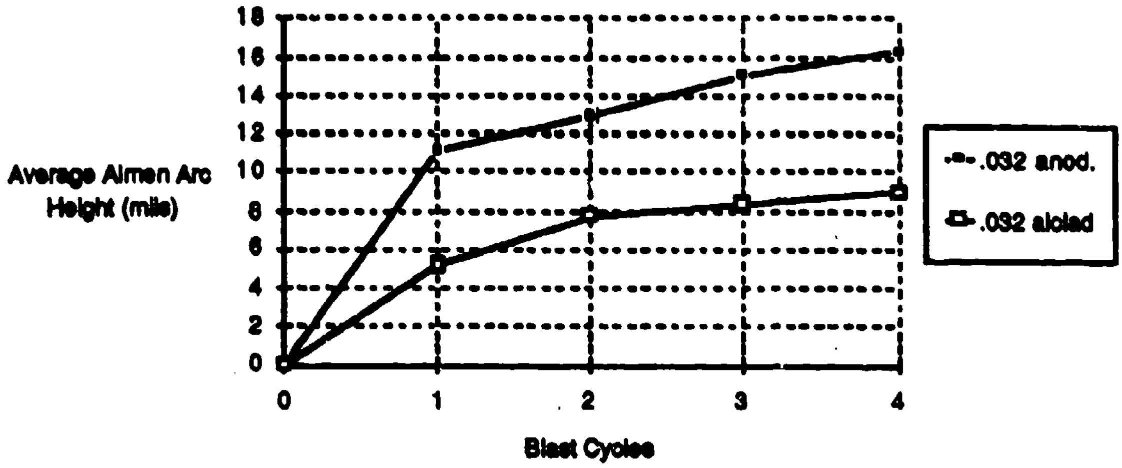


Figure 3.5 Comparative Average Arc Heights - 2024-T3 0.032 inch Anodized and 2024-T3 0.032 inch Alclad Aluminum

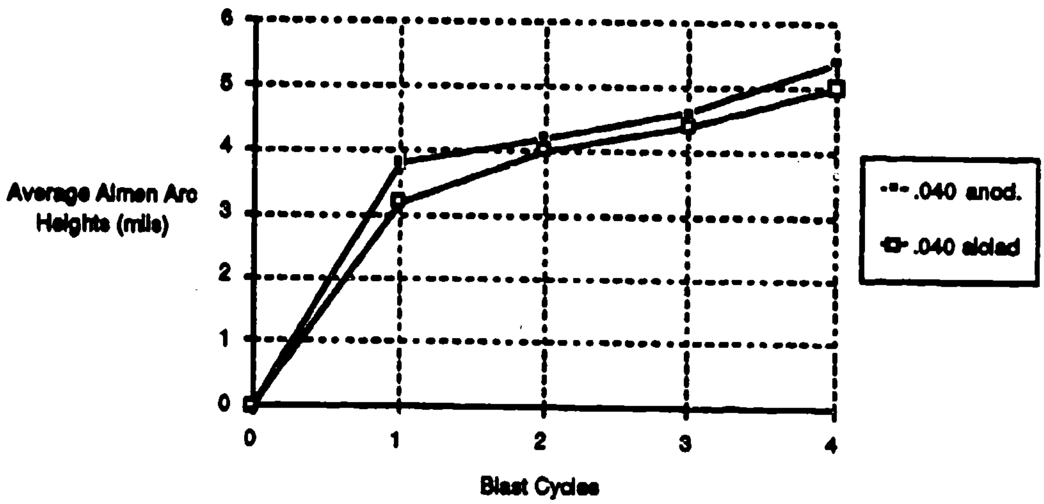


Figure 3.6 Comparative Average Arc Heights - 2024-T3 0.040 inch Anodized and 2024-T3 0.040 inch Alclad Aluminum

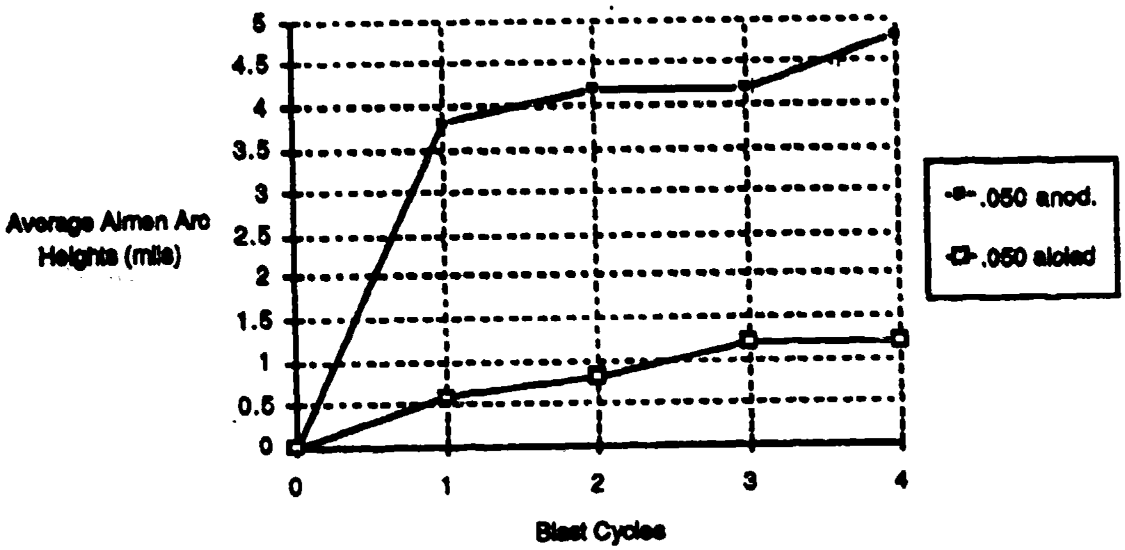


Figure 3.7 Comparative Average Arc Heights - 2024-T3 0.050 inch Anodized and 2024-T3 0.050 inch Alclad Aluminum

3.3 FATIGUE CRACK PROPAGATION TEST RESULTS

A fatigue crack propagation test program was performed to supplement the existing crack growth data for 2024-T3 aluminum in anodized and alclad treatments identified through the technical search. The crack propagation test parameters used, such as the stress ratio and specimen dimensions, are contained in Appendix C.

The fatigue crack propagation tests, performed using ASTM specification E647-83, showed no significant increase in the crack growth rate for the anodized 2024-T3 aluminum after it had been blasted with plastic media. The crack size versus cycles plots for the anodized 2024-T3 aluminum in 0.032, 0.040, and 0.050 inch thicknesses are plotted in figures 3.8, 3.9, and 3.10, respectively, and its crack growth data counterpart are represented in figures 3.14, 3.15, and 3.16. From examination of these plotted data it can be seen that the material experienced retardation effects due to the intense blast of the procedure and the selected agressive parameters.

There were significant increases in the crack growth rate for the alclad 2024-T3 aluminum shown by the fatigue crack propagation test results. Figures 3.11, 3.12, 3.13 graphically illustrates the crack size versus cycles and figures 3.17, 3.18, and 3.19 contain plots of the crack growth data for the alclad 2024-T3 aluminum in 0.032, 0.040, and 0.050 inch thicknesses, respectively. These curves show that the crack growth rate significantly increased in the blasted material for all three thicknesses. This increase was most noticeable in the 0.032 inch thickness.

Comparison of the crack growth rate curves for the blasted specimens relative to material thickness was not significant for the anodized aluminum but the alclad aluminum showed a different behavior. The crack growth rates for the blasted anodized 2024-T3 aluminum showed essentially no difference relative to material thickness. Table 3.6 presents the fatigue crack growth rates results, at different dK, of all the specimens tested. Figure 3.20 demonstrates this by providing a plot of the crack growth rates for the blasted anodized substrate in all three thicknesses. For the alclad 2024-T3 aluminum the crack growth rates for the blasted material increased as the material thickness decreased. This trend is shown in figure 3.21, which plots the crack growth curves for the blasted alclad substrate in all three thicknesses.

FIGURE 3.8 CRACK SIZE VS CYCLES - 0.032", 2024-T3, ANODIZED

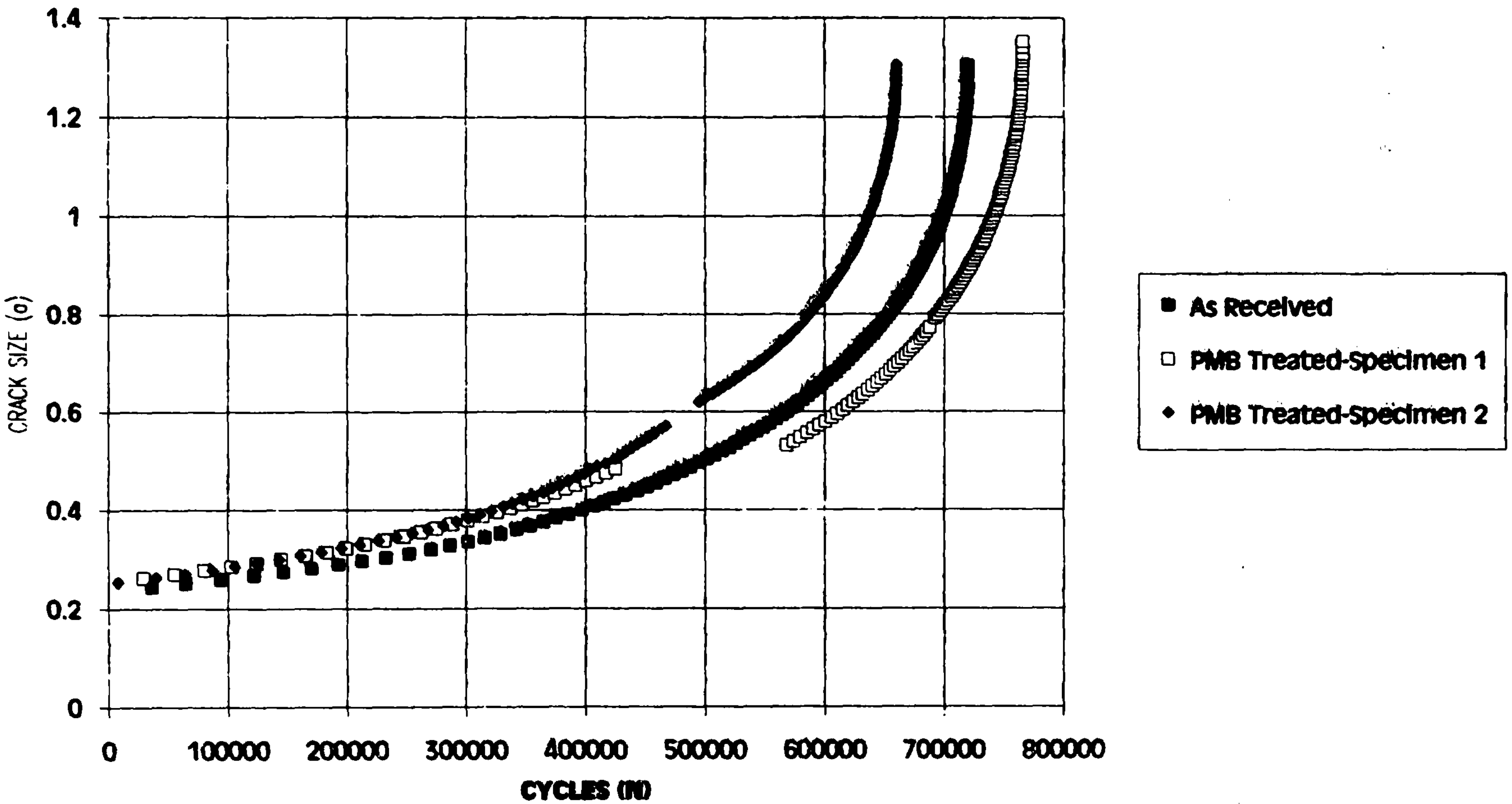


FIGURE 3.9 CRACK SIZE VS CYCLES - 0.040", 2024-T3, ANODIZED

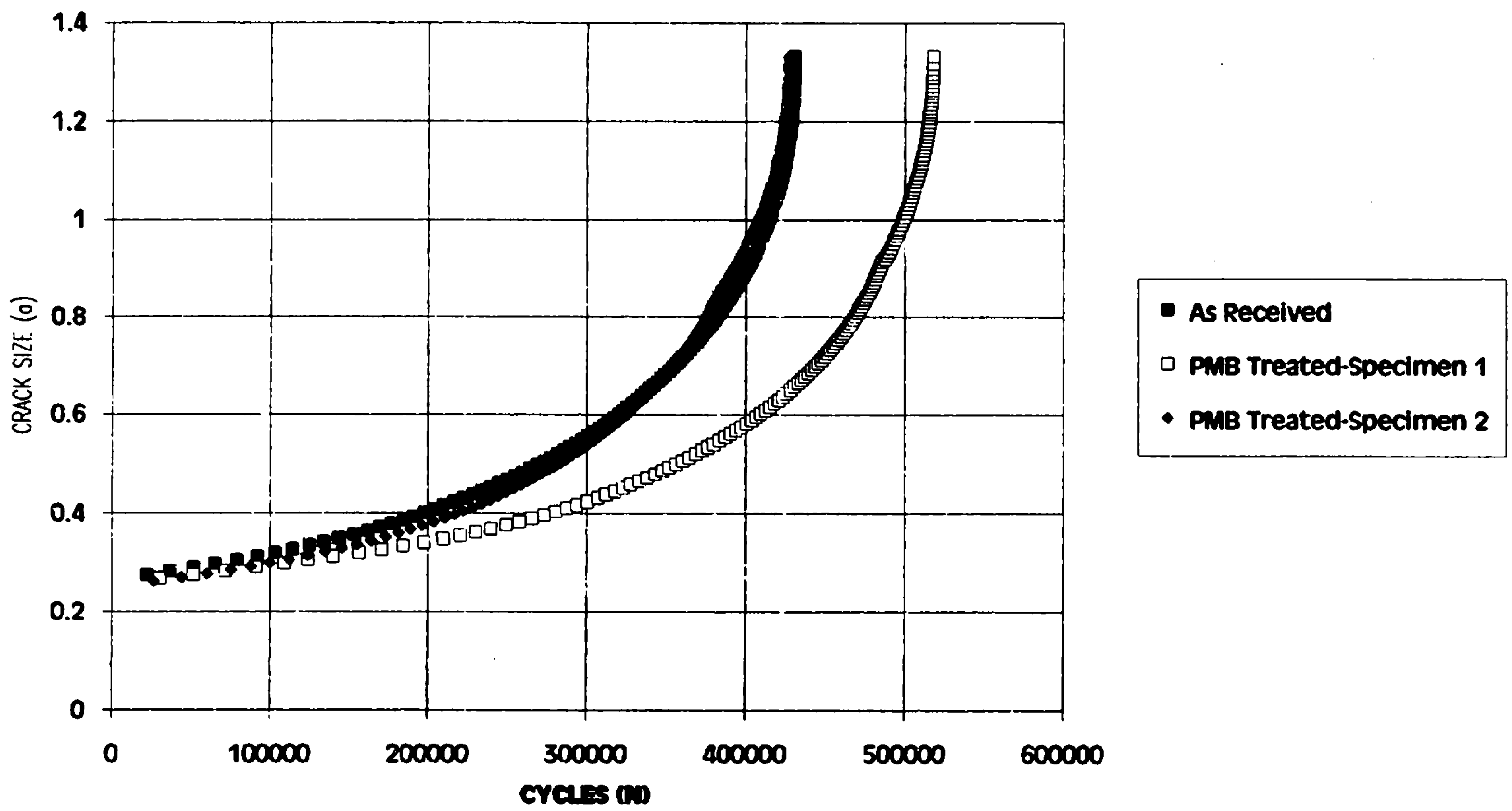


FIGURE 3.10 CRACK SIZE VS CYCLES - 0.05", 2024-T3, ANODIZED

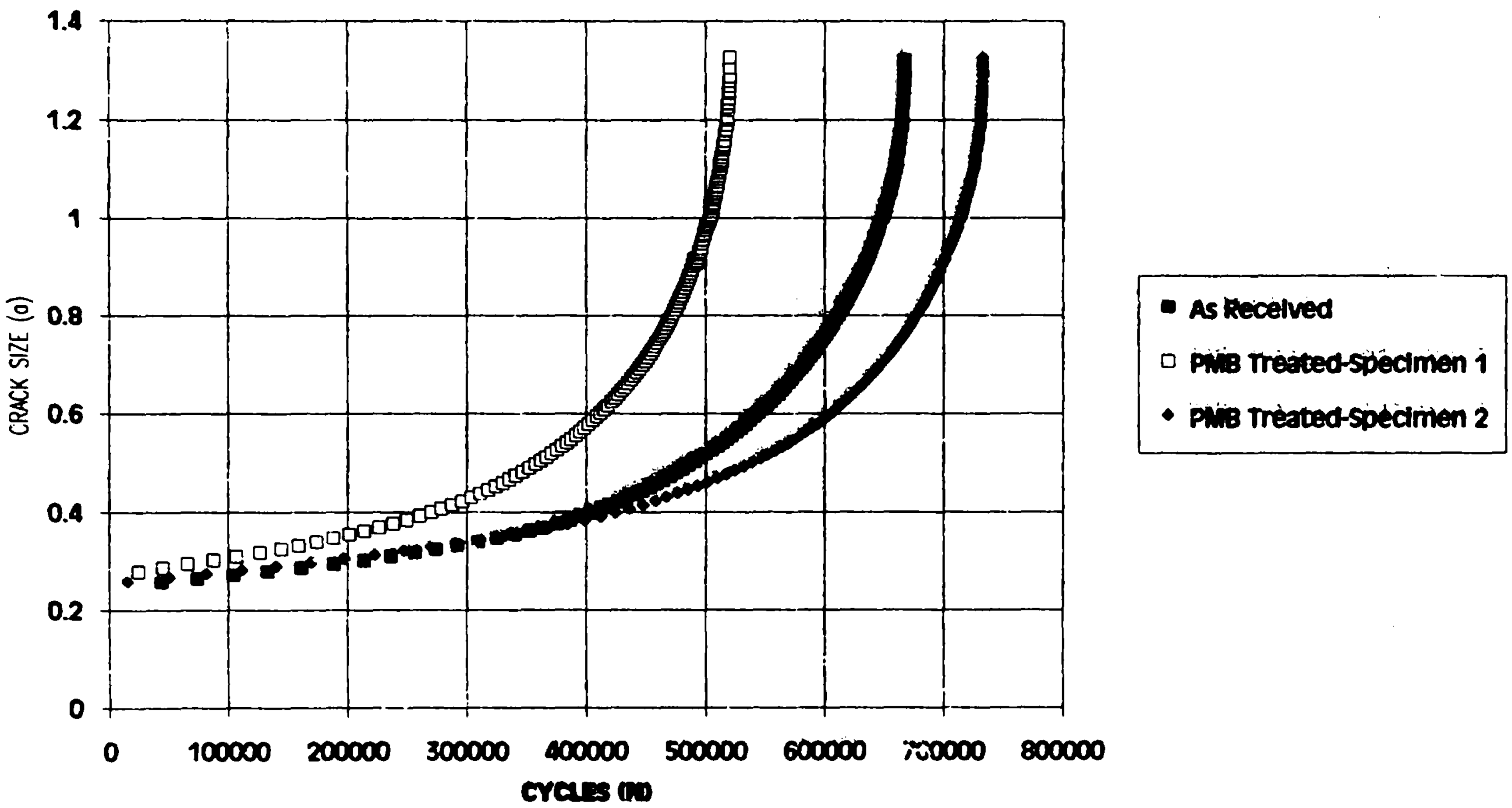


FIGURE 3.11 CRACK SIZE VS CYCLES - 0.032", 2024-T3, ALCLAD

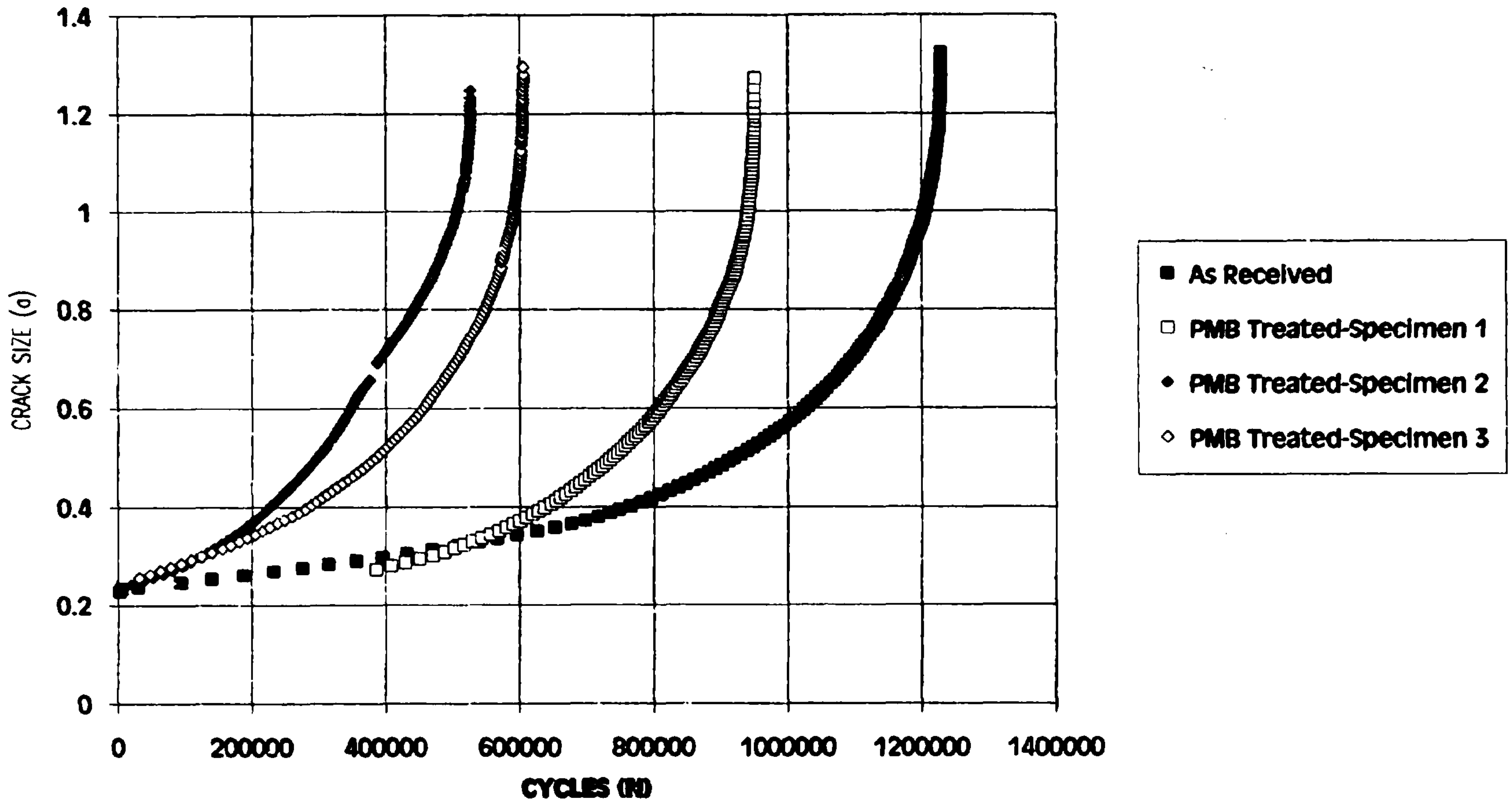


FIGURE 3.12 CRACK SIZE VS CYCLES - 0.040", 2024-T3, ALCLAD

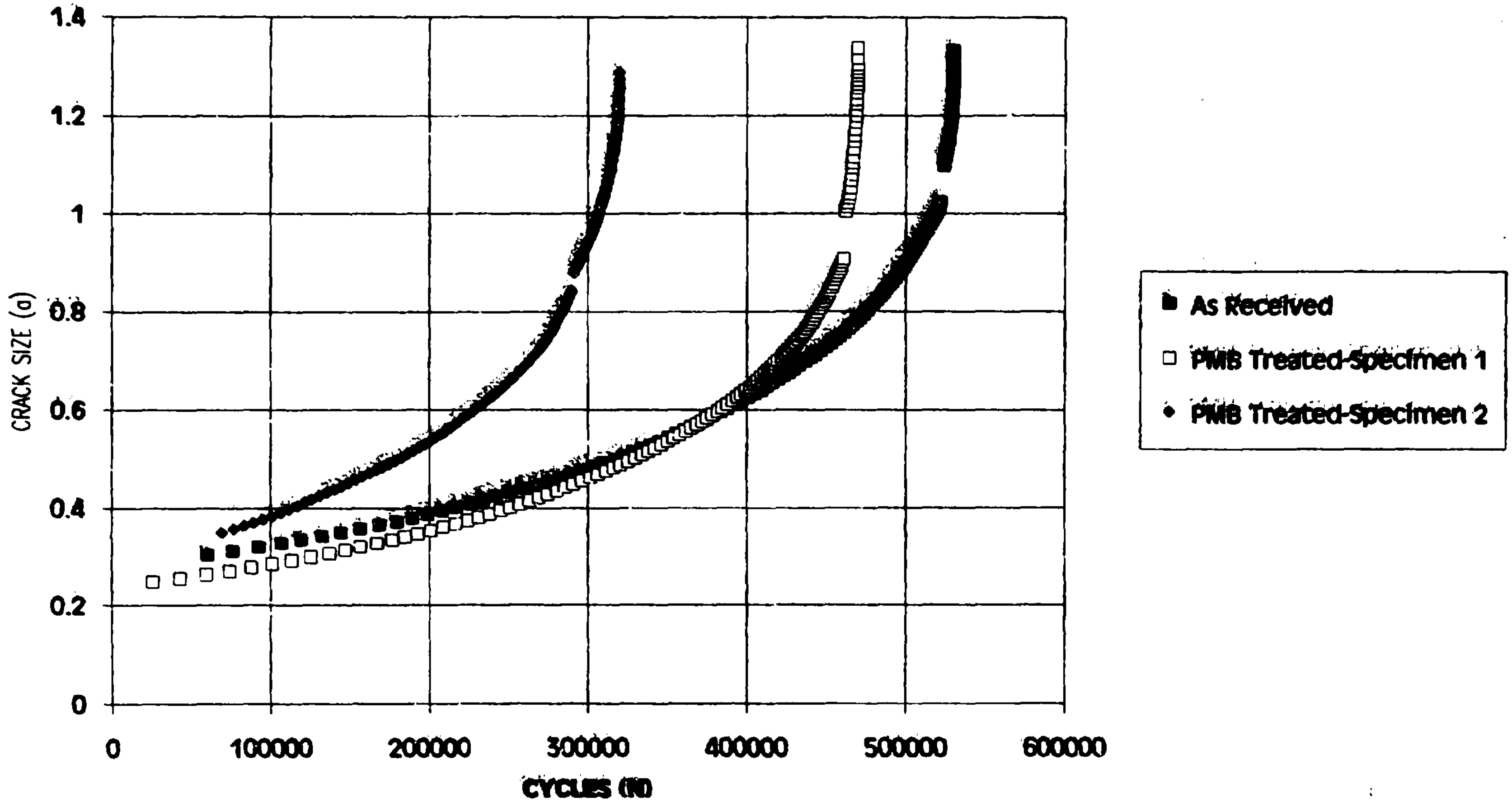
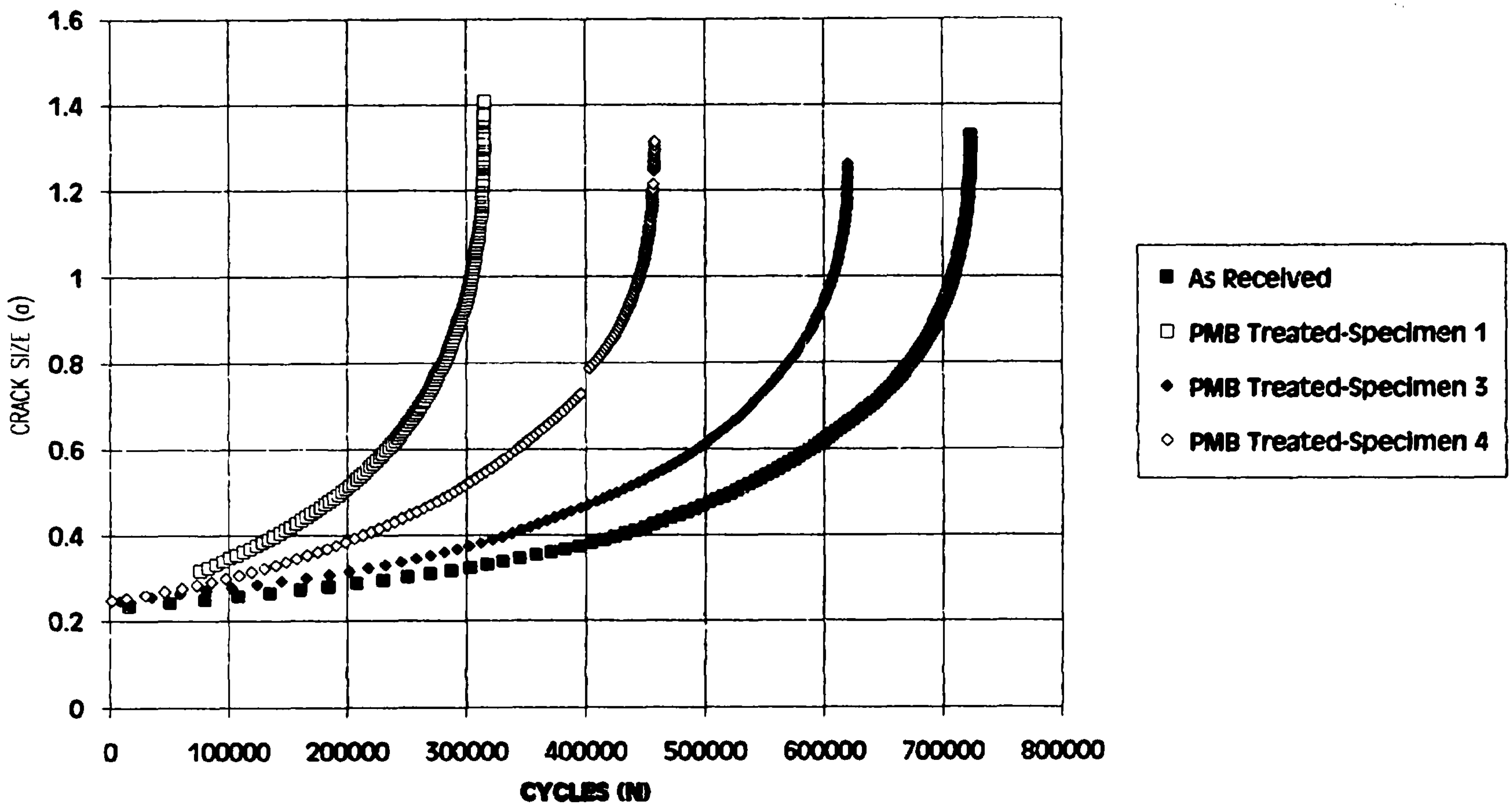


FIGURE 3.13 CRACK SIZE VS CYCES - 0.050" , 2024-T3, ALCLAD



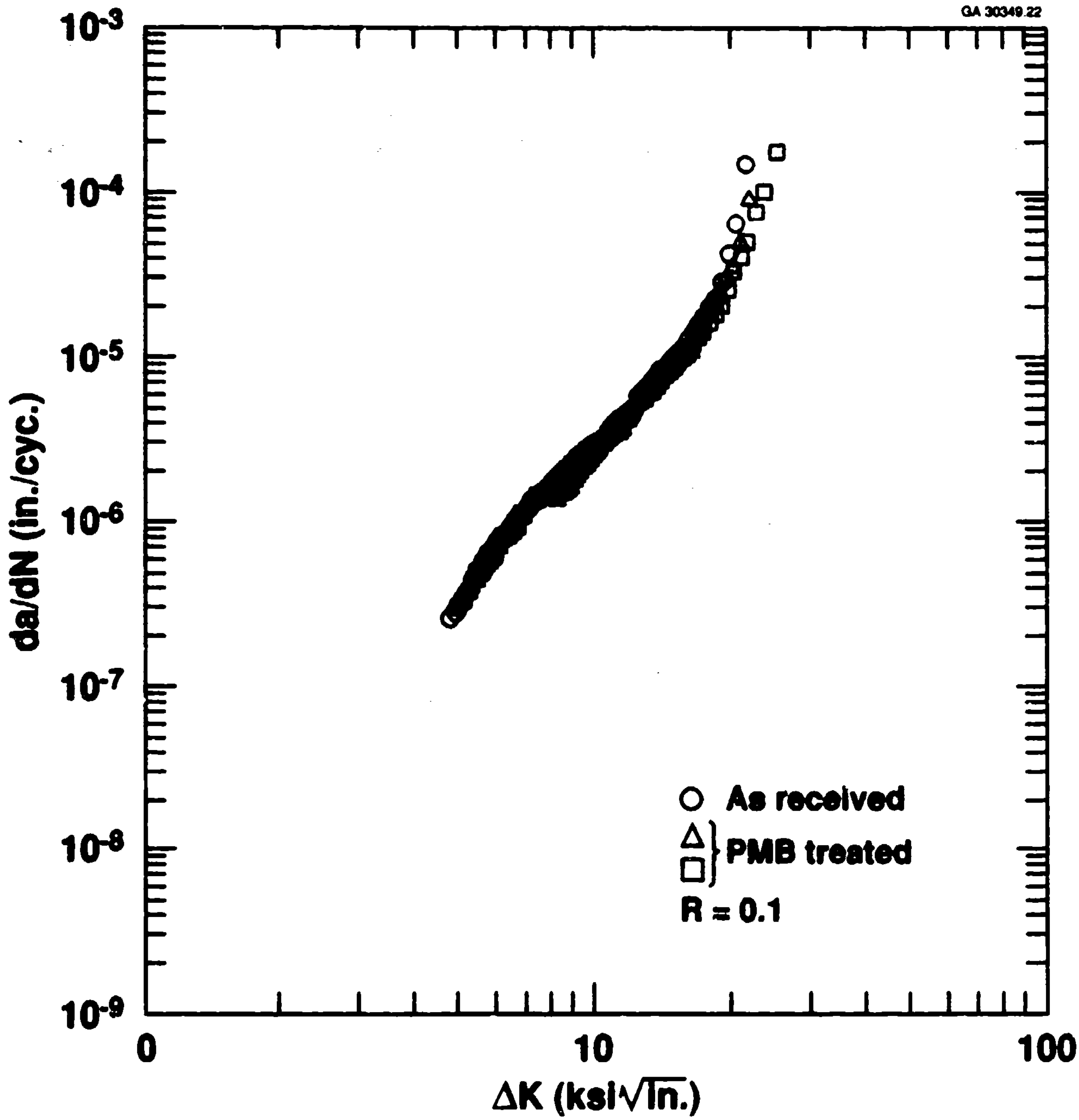


Figure 3.14 Effect of PMB Stripping on Fatigue Crack Propagation 0.032 in. Anodized 2024-T3 Sheet

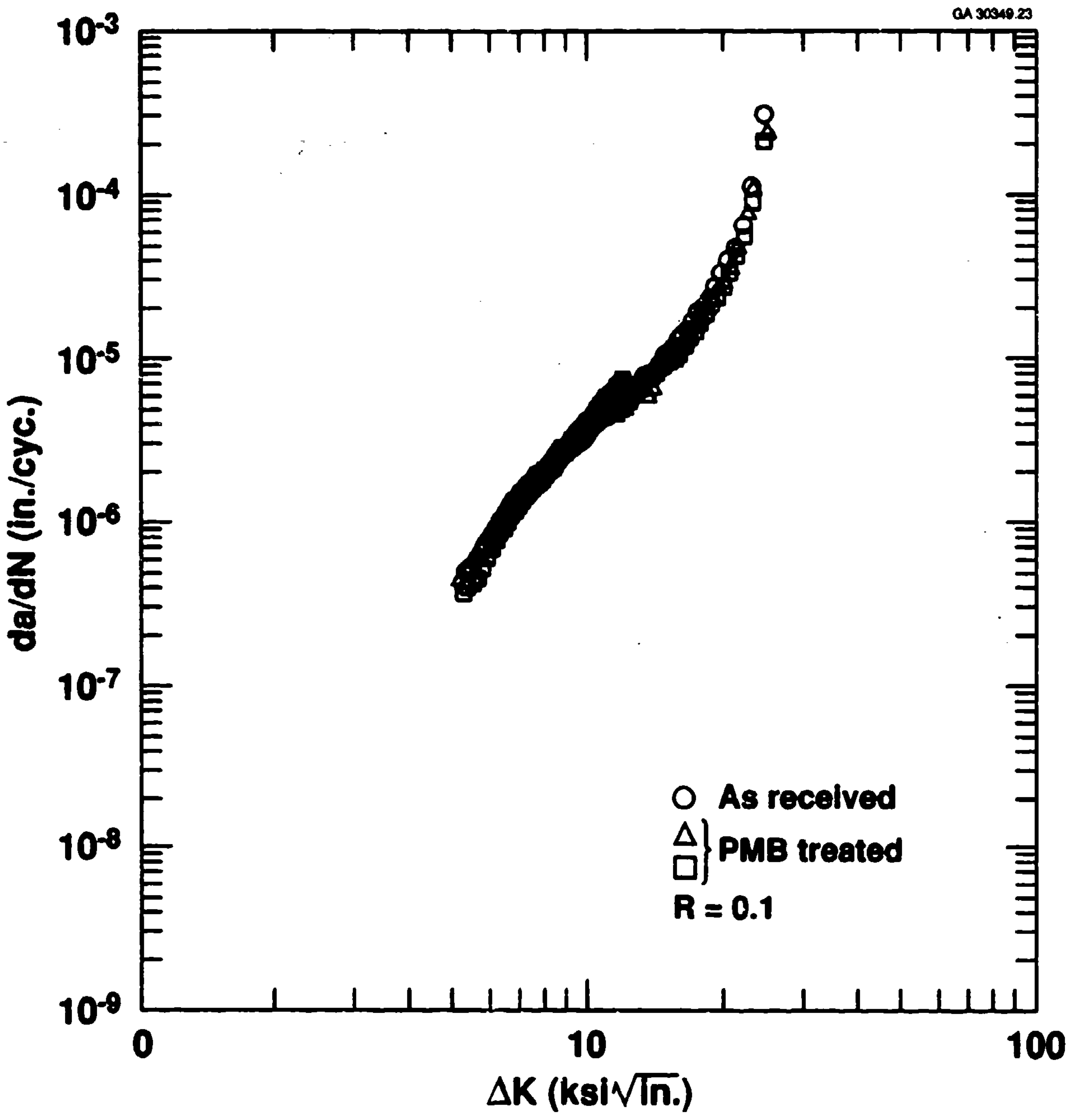


Figure 3.15 Effect of PMB Stripping on Fatigue Crack Propagation 0.040 in. Anodized 2024-T3 Sheet

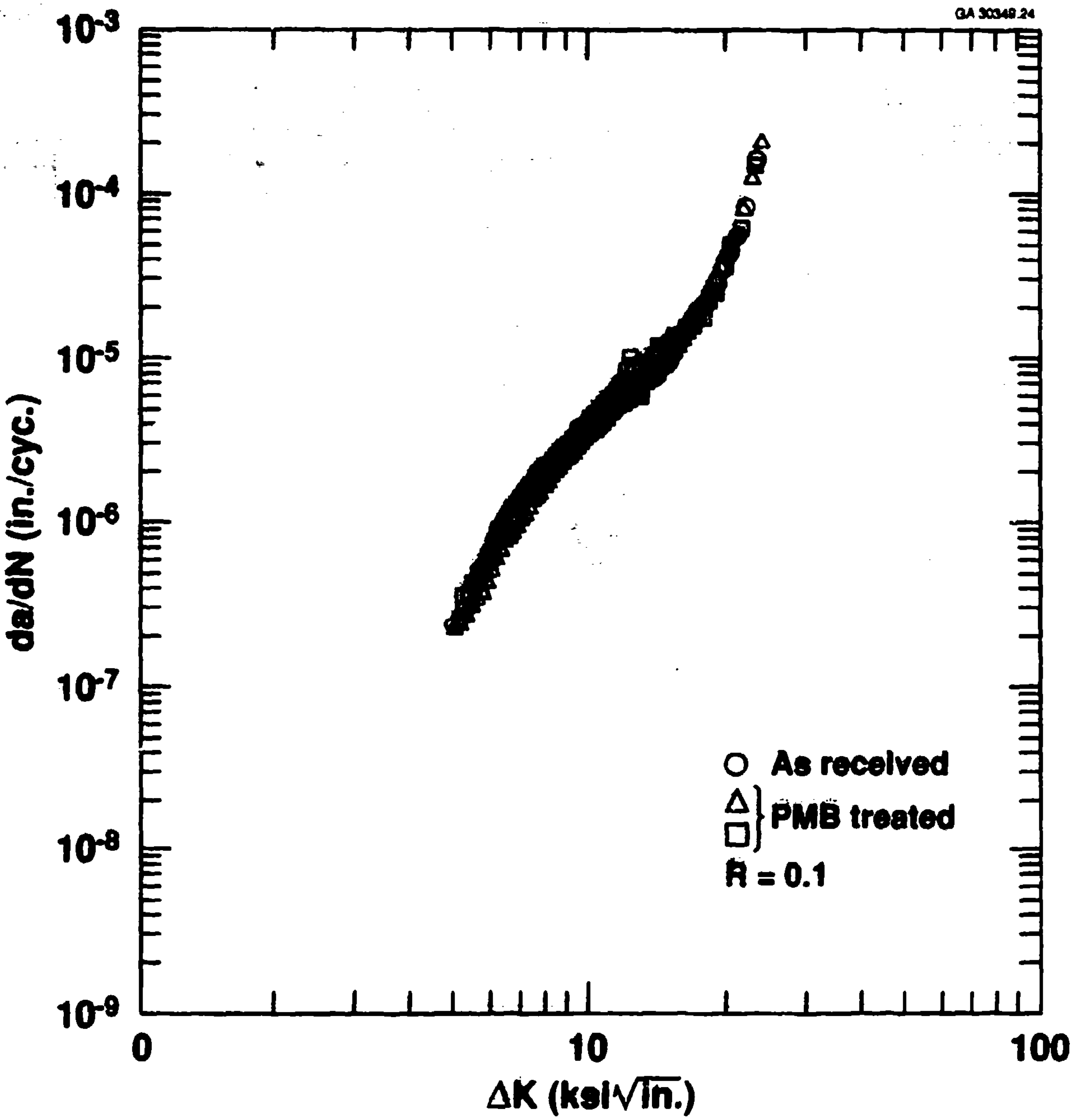


Figure 3.16 Effect of PMB Stripping on Fatigue Crack Propagation 0.050 in. Anodized 2024-T3 Sheet

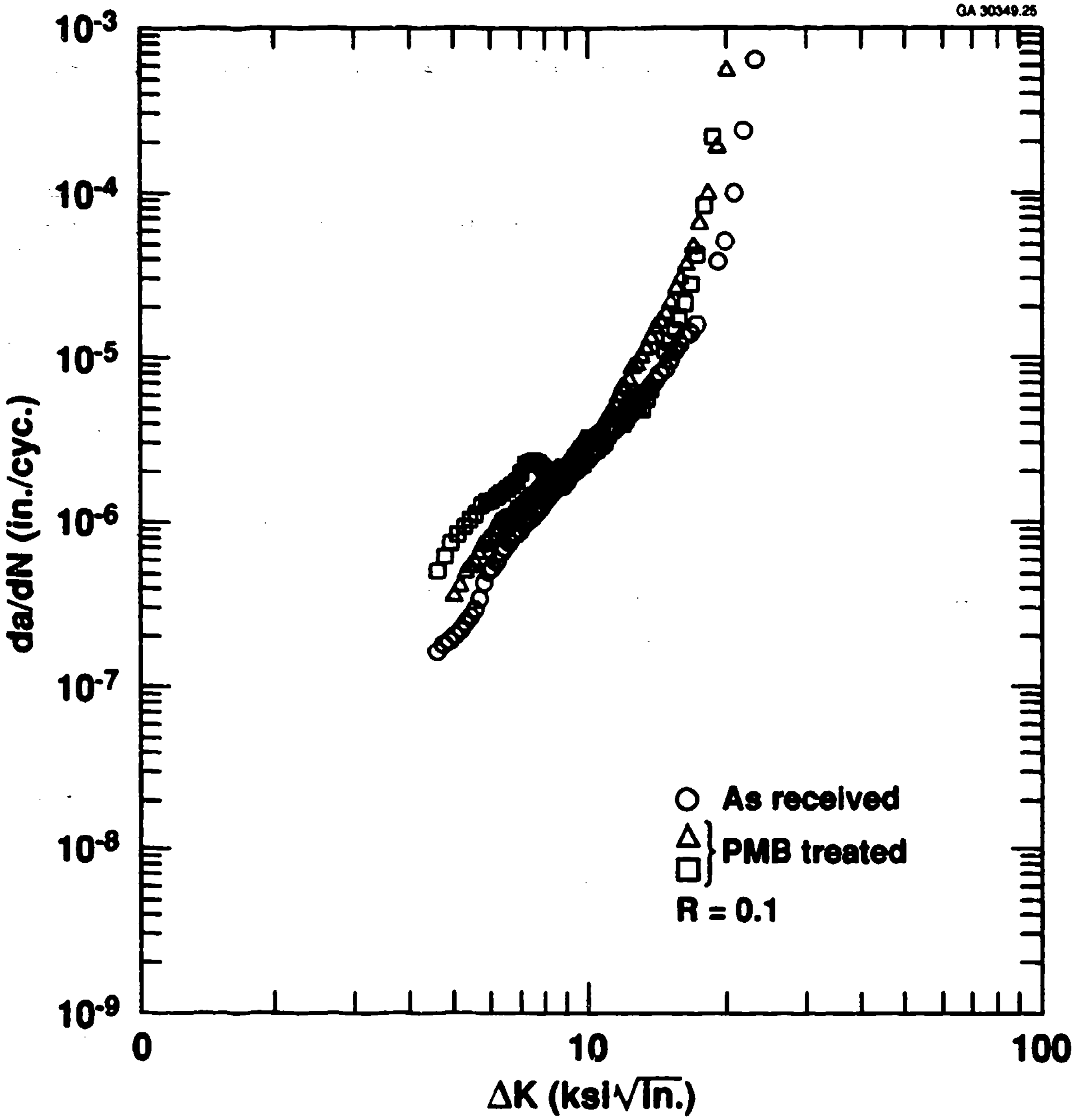


Figure 3.17 Effect of PMB Stripping on Fatigue Crack Propagation 0.032 in. Alclad 2024-T3 Sheet

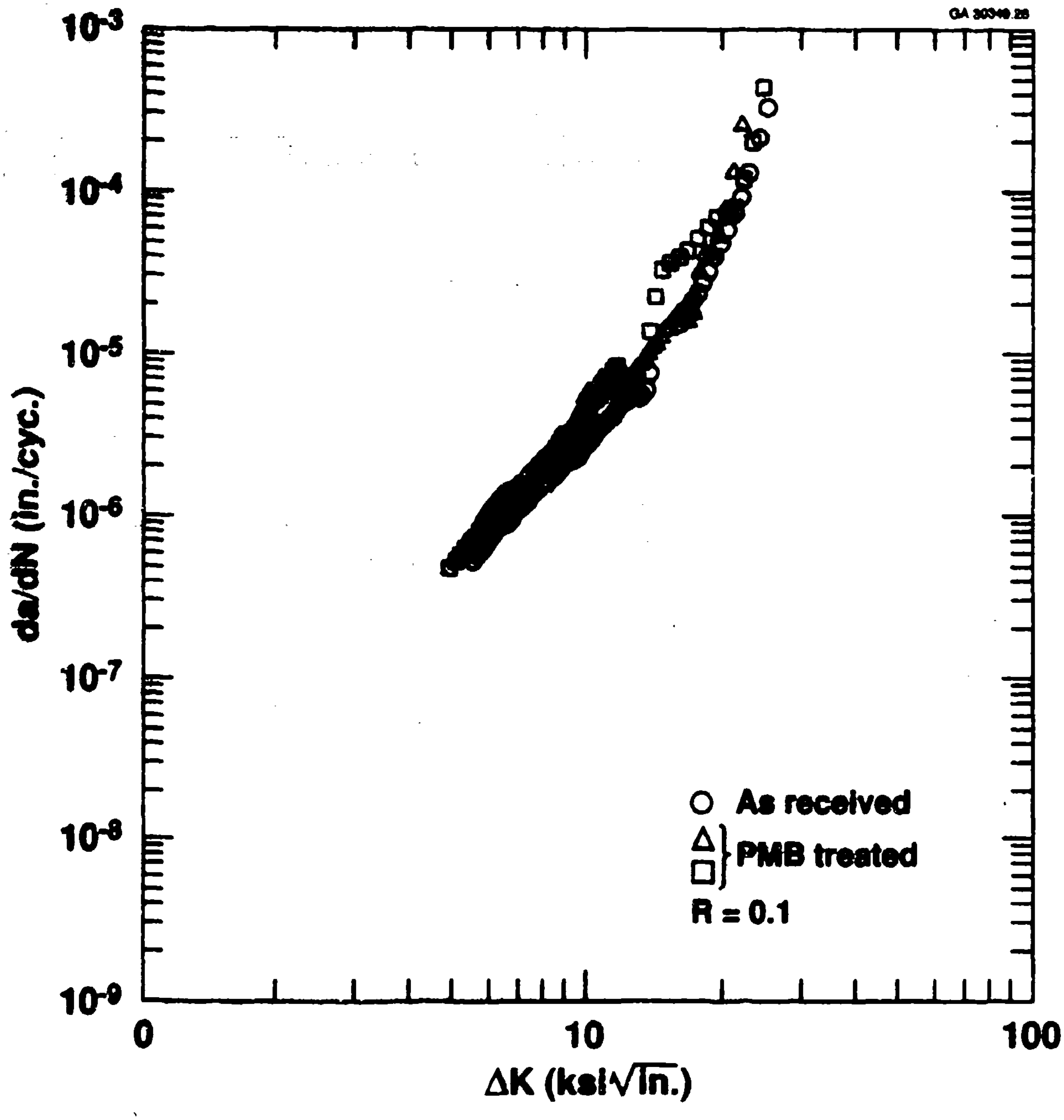


Figure 3.18 Effect of PMB Stripping on Fatigue Crack Propagation 0.040 in. Alclad 2024-T3 Sheet

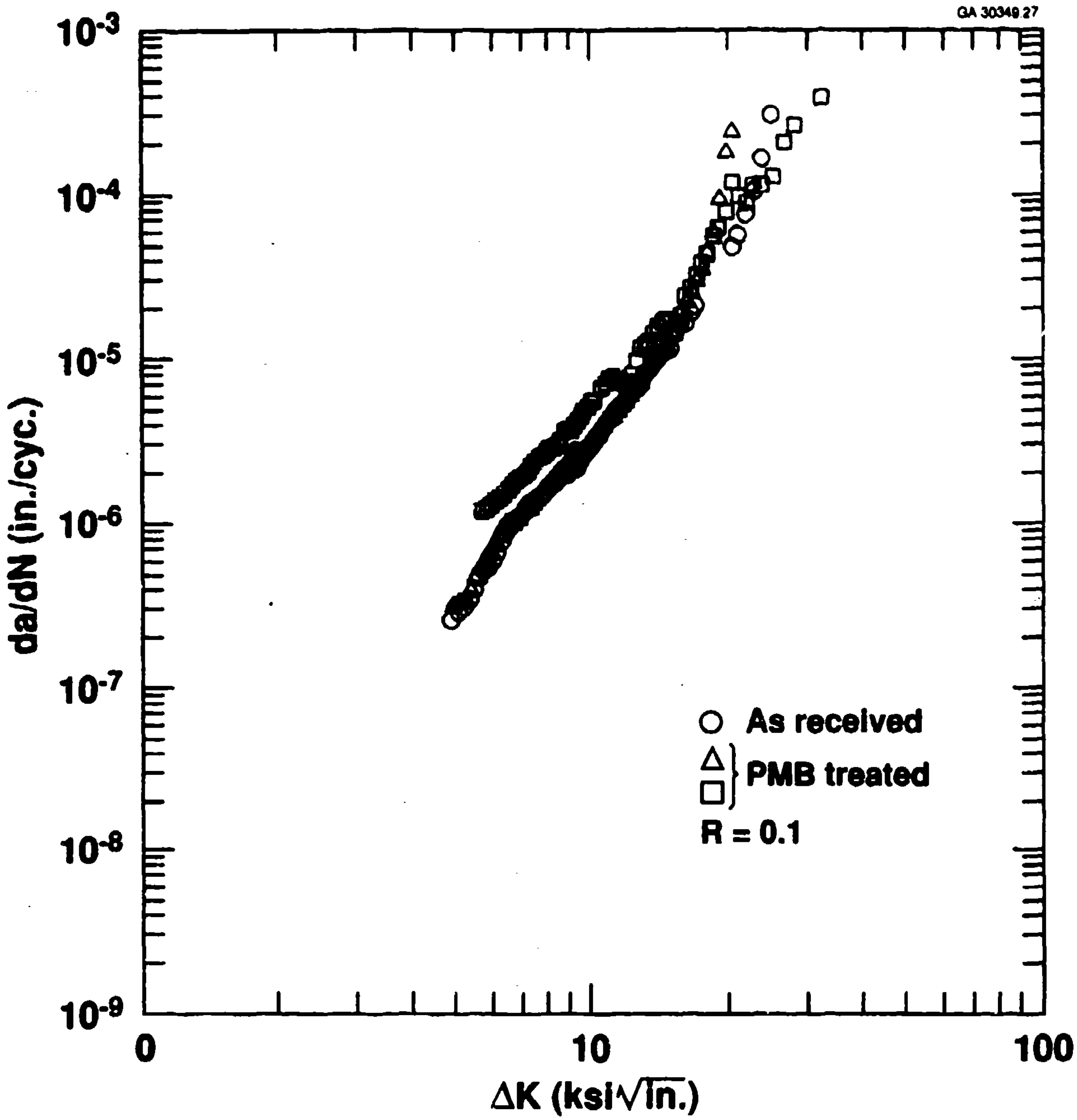


Figure 3.19 Effect of PMB Stripping on Fatigue Crack Propagation 0.050 in. Alclad 2024-T3 Sheet

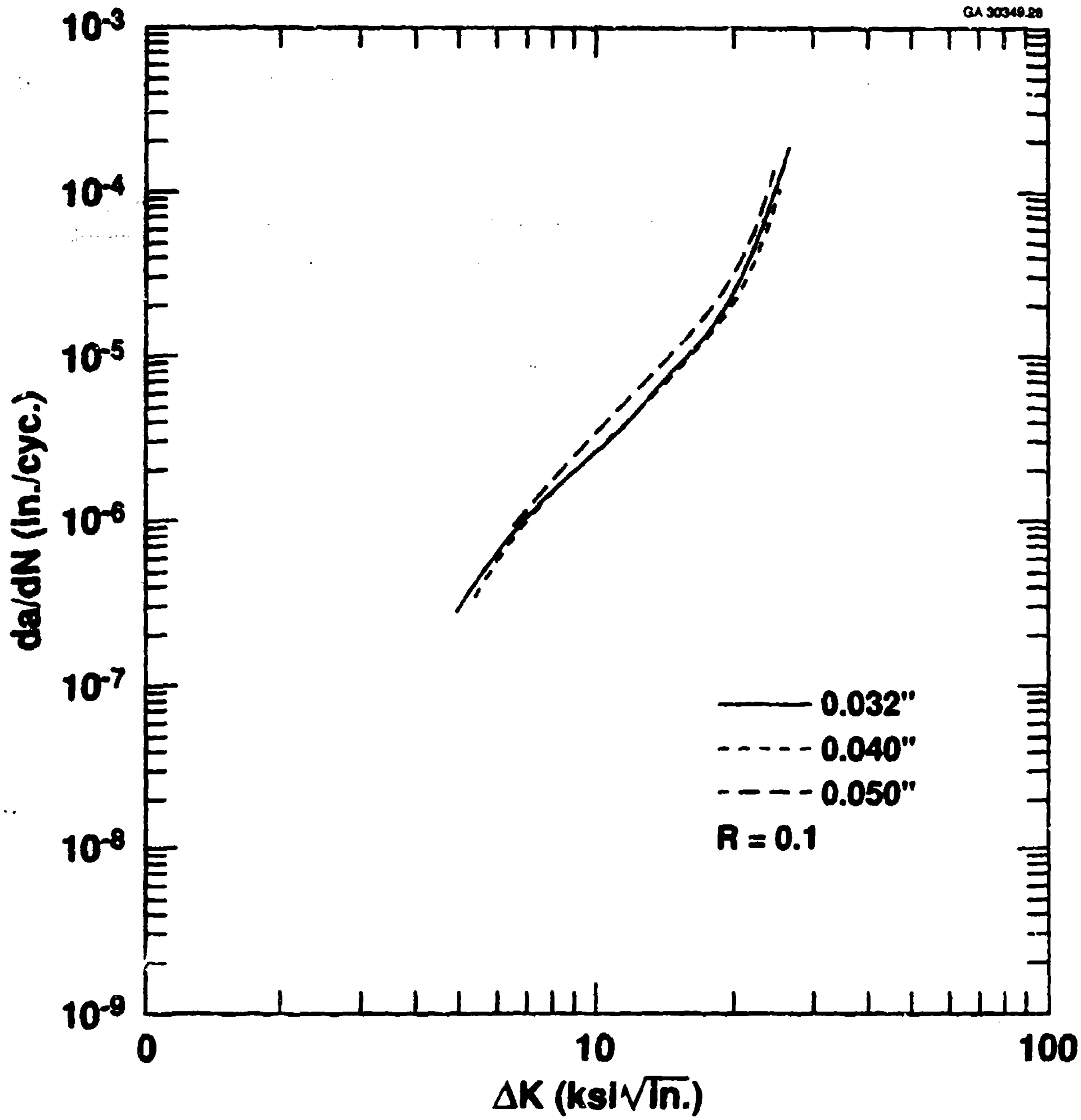


Figure 3.20 Fatigue Crack Growth-PMB Treated Anodized 2024-T3 Sheet

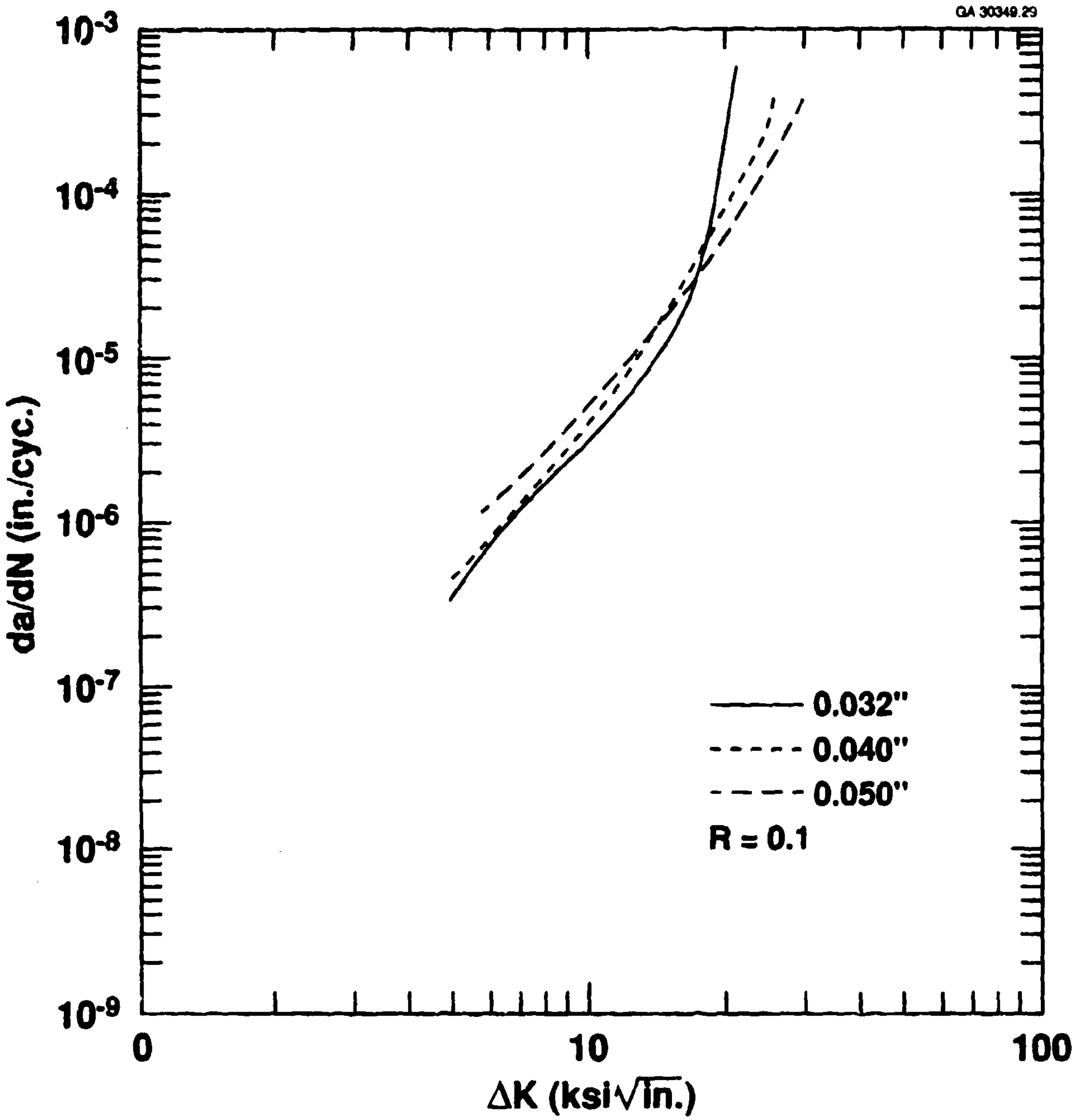


Figure 3.21 Fatigue Crack Growth-PMB Treated Alclad 2024-T3 Sheet

TABLE 3.6 FATIGUE CRACK GROWTH RESULTS

ALCLAD 2024-T3

dK	da/dN						CRACK GROWTH INCREMENT FACTOR		
	AS RECEIVED			PMB TREATED (4 BLASTS)					
	0.032"	0.04"	0.050"	0.032"	0.04"	0.050"	0.032"	0.04"	0.050"
5	1.802E-07	4.713E-07	2.893E-07	4.870E-07	5.125E-07	4.948E-07	2.70	1.09	1.71
	1.802E-07	-	2.893E-07	3.413E-07	-	3.376E-07	1.89	-	1.17
	1.802E-07	-	2.893E-07	7.376E-07	-	-	4.09	-	-
7	7.93E-07	1.264E-06	1.184E-06	1.177E-06	1.434E-06	1.973E-06	1.48	1.13	1.67
	7.93E-07	1.264E-06	1.184E-06	1.762E-06	1.612E-06	1.479E-06	2.22	1.28	1.25
	7.93E-07	-	1.184E-06	1.286E-06	-	1.256E-06	1.62	-	1.06
10	2.318E-06	3.138E-06	3.031E-06	3.017E-06	4.621E-06	3.184E-06	1.30	1.47	1.05
	2.318E-06	3.138E-06	3.031E-06	3.094E-06	6.392E-06	5.877E-06	1.33	2.04	1.94
	2.318E-06	-	3.031E-06	2.472E-06	-	-	1.07	-	-
15	8.707E-06	1.195E-05	1.287E-06	1.969E-05	3.749E-05	1.464E-06	2.26	3.14	1.13
	8.707E-06	1.195E-05	1.287E-05	1.673E-05	1.484E-05	1.509E-05	1.92	1.24	1.17
	8.707E-06	-	1.287E-05	1.145E-05	-	1.923E-05	1.32	-	1.49

ANODIZED 2024-T3

dK	da/dN						CRACK GROWTH INCREMENT FACTOR		
	AS RECEIVED			PMB TREATED (4 BLASTS)					
	0.032"	0.04"	0.050"	0.032"	0.04"	0.050"	0.032"	0.04"	0.050"
5	3.187E-07	4.983E-07	2.643E-07	3.253E-07	4.776E-07	2.505E-07	1.02	0.96	0.95
	3.187E-07	4.983E-07	2.643E-07	3.893E-07	3.797E-07	3.623E-07	1.22	0.76	1.37
7	1.230E-06	1.463E-06	1.453E-06	1.337E-06	1.343E-06	1.300E-06	1.09	0.92	0.89
	1.230E-06	1.463E-06	1.453E-06	-	1.734E-06	1.470E-06	-	1.19	1.01
10	3.170E-06	3.170E-06	3.730E-06	2.828E-06	3.974E-06	3.833E-06	0.89	1.25	1.03
	3.170E-06	3.170E-06	3.730E-06	3.208E-06	4.905E-06	4.490E-06	1.01	1.55	1.20
15	1.124E-05	1.195E-05	9.970E-06	9.676E-06	1.030E-05	1.098E-05	0.86	0.86	1.10
	1.124E-05	1.195E-05	9.970E-06	9.867E-06	1.062E-05	1.098E-05	0.88	0.89	1.10

Table 3.7 Effect of Plastic Media Blasting (PMB) Treatments on thickness of Protective Layers

Material Thickness (inches)	Thickness of Coating, inches			
	Anodized		Alclad	
	As Received	PMB Treated	As Received	PMB Treated
0.032	0.000197	0.000158	0.00182	0.00052 - 0.00236
0.040	0.000151	0.000115	0.00212	0.00042 - 0.00242
0.050	0.000204	0.000191	0.00285	0.00054 - 0.00325

A comparison of the crack growth results with the Almen strip results from section 3.2 illustrates how blast parameters can cause substrate damage. The anodized aluminum arc heights were consistently higher than the alclad arc heights for each thickness. However, the crack growth rate in the anodized material was essentially unchanged before and after blasting and that of the alclad material was increased for all thicknesses. The higher arc heights for the anodized material can be attributed to the lack of a cushioning clad surface layer. The increased crack growth rate, in the alclad material, can be attributed to residual stress and surface flaws. From figures 3.11 to 3.13 it can be seen that after plastic media blasting, the alclad material crack length significantly increased at a lower life cycle (more than 50% reduction) when compared to the "as received" (control) specimen.

3.4 COATING REMOVAL AND SURFACE ROUGHNESS RESULTS

Determination of the depth of anodized and alclad coating removed and the surface roughness was made to assess the effect of plastic media blasting on these corrosion resistant surface treatments.

The results of measurements made to determine the thickness of the anodized and alclad protective layers before and after plastic media treatment for all three thicknesses are listed in table 3.7. It can be seen that the anodized coating was not significantly affected relative to the alclad coating. The maximum percentage loss in anodized layer thickness was 24 percent for the 0.040 inch thickness while the maximum percentage loss for the alclad layer was 81 percent for the 0.050 inch thickness. In addition, the post-treatment alclad layer measurements greater than the original thickness measurements indicate that the soft aluminum cladding was shifted by the blast stream into peaks.

The surface roughness measurements made to determine the effect of the plastic media blast on the surface of the test specimens are listed in table 3.8. The average surface roughness measurements (Ra - the arithmetic mean of departures from the mean line) and the maximum peak to valley measurements (Ry) indicate that the anodized surface roughness was not vitally affected by the plastic media treatment but the alclad surface roughness was increased. This supports the observations made in measuring the thickness of the protective layers that were removed.

3.5 SCANNING ELECTRON MICROSCOPE PHOTOGRAPHS

Scanning Electron Microscope (SEM) photographs were taken to provide visual data regarding the growth of the cracks and the effect of plastic media blasting on the surface treatments. It was noticed during the fatigue crack propagation tests of the PMB treated alclad specimens that visual crack measurements on the blasted side generally trailed those on the unblasted side. This effect was investigated through SEM photography of the crack surface.

The observations made regarding the surface damage of the blasted alclad surfaces is confirmed by the SEM photographs. Figures 3.22 through 3.25 display SEM photographs taken of the anodized material before blasting for 0.032 inch thickness, and after blasting for all three thicknesses. The pictures show no significant surface damage as a result of the plastic media blasting treatment. Figures 3.26 through 3.29, which contain similar views for the alclad aluminum, show the significant and extensive surface pitting caused by the plastic media blasting.

Table 3.8 Surface Roughness Measurements - Surtronic 4

ID	Alloy (a)	Thickness inch	PMB Treated	Ra (b) micro inch 1.00	2.00	3.00	4.00	5.00	Average	Ry(c) Max u inch
AN32-2	2024-T3a	0.032	NO	25.59	19.29	19.29	22.05	18.90	21.02	282.28
AN32-1	2024-T3a	0.032	YES	20.87	24.02	21.26	27.56	29.53	24.65	286.61
AN40-2	2024-T3a	0.04	NO	29.92	27.56	27.56	26.38	28.35	27.95	226.38
AN40-1	2024-T3a	0.04	YES	26.77	29.53	27.56	25.59	29.13	27.72	253.94
AN50-2	2024-T3a	0.05	NO	11.81	12.99	12.99	12.99	12.20	12.60	171.26
AN50-1	2024-T3a	0.05	YES	16.54	21.26	17.32	18.11	18.11	18.27	176.77
AL32-2	Alc 2024-T3	0.032	NO	9.45	20.47	9.84	17.32	14.96	14.41	274.02
AL32-1	Alc 2024-T3	0.032	YES	253.94	253.94	235.43	262.60	247.24	250.63	2059.05
AL40-2	Alc 2024-T3	0.04	NO	9.45	20.47	9.84	17.32	14.96	14.41	274.02
AL40-1	Alc 2024-T3	0.04	YES	176.77	191.34	162.99	172.05	183.86	177.40	1429.13
AL50-2	Alc 2024-T3	0.05	NO	11.81	18.50	5.91	15.35	13.39	12.99	187.40
AL50-1	Alc 2024-T3	0.05	YES	241.34	279.53	263.39	254.72	277.16	263.23	1799.21

NOTES:

a 2024-T3 sheet anodized and sealed

b Ra is the arithmetic mean of departures from the mean line

c Ry is the largest peak to valley height in the lengths analyzed

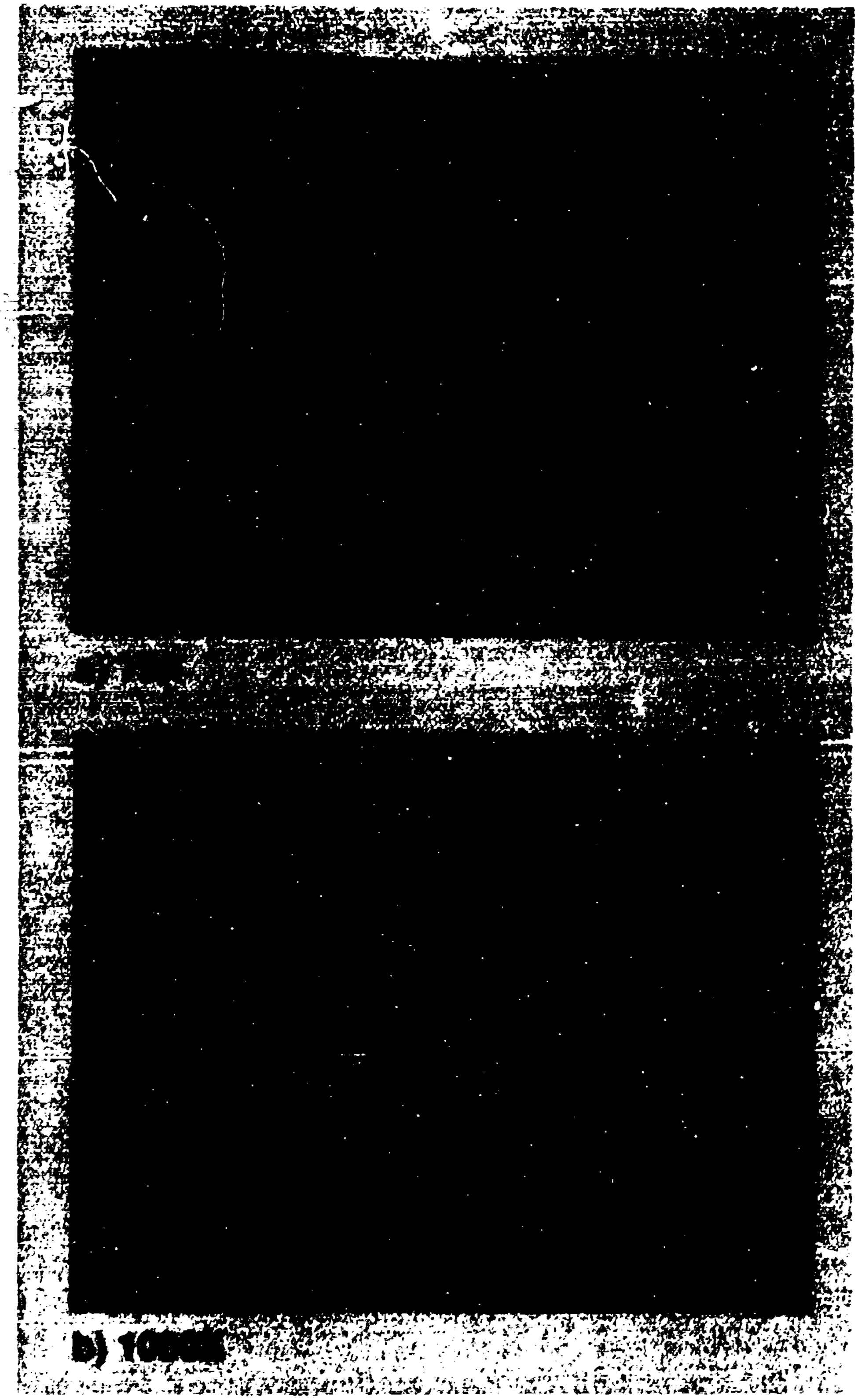


Figure 3.22 Untreated 0.032 in. Anodized 2024-T3 Sheet

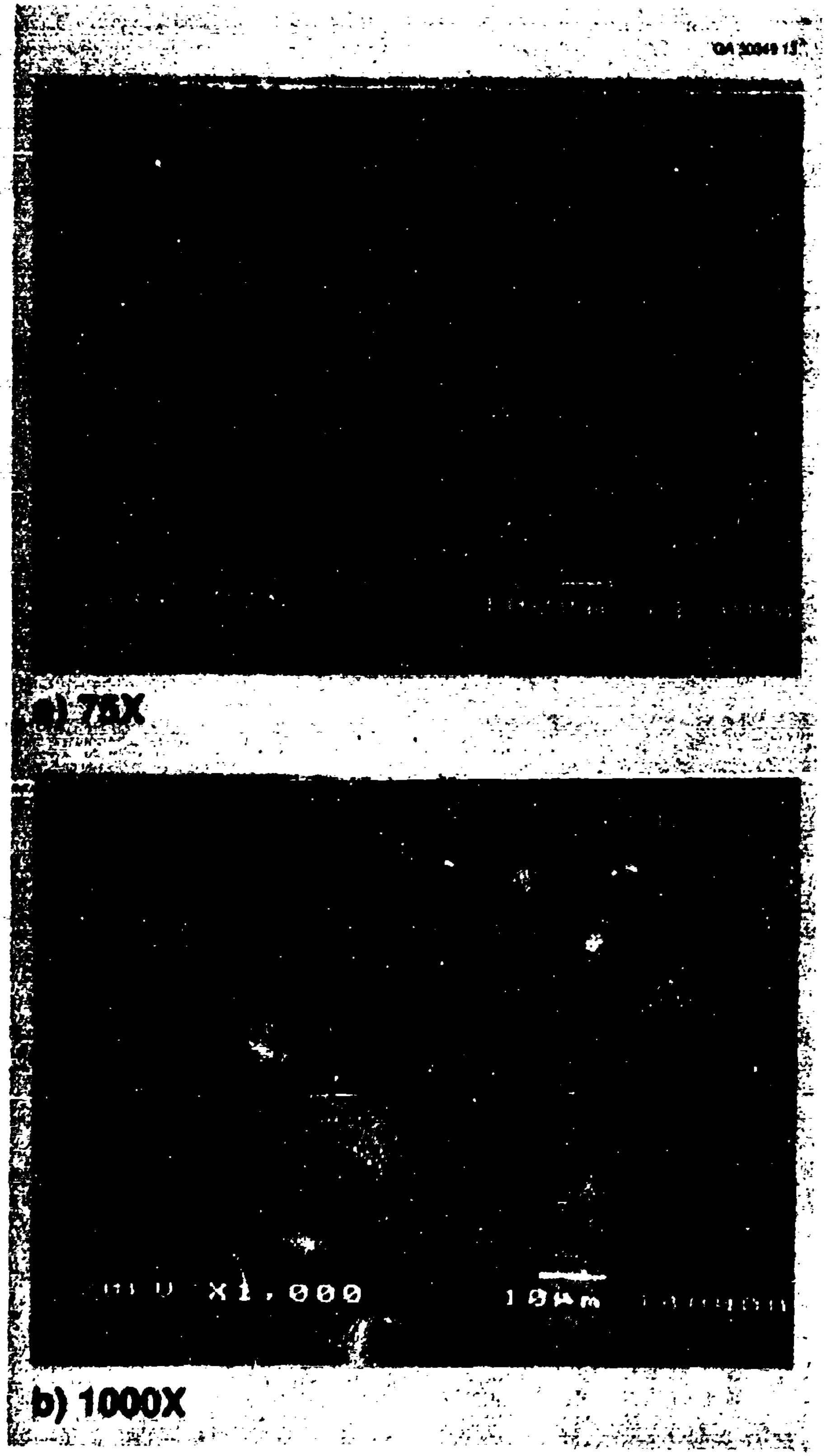


Figure 3.23 PMB Treated 0.032 in. Anodized 2024-T3 Sheet

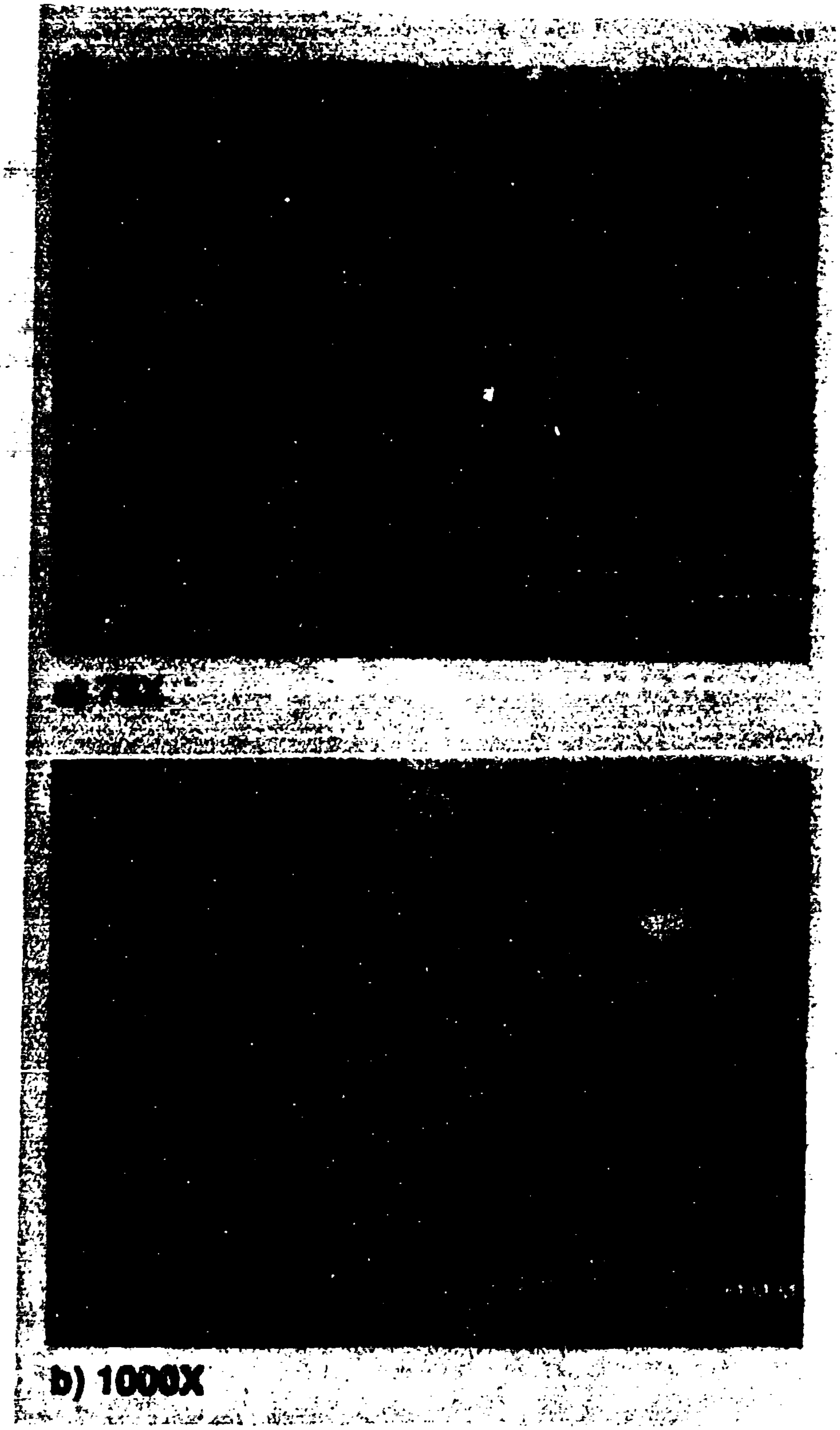


Figure 3.24 PMB Treated 0.040 in. Anodized 2024-T3 Sheet

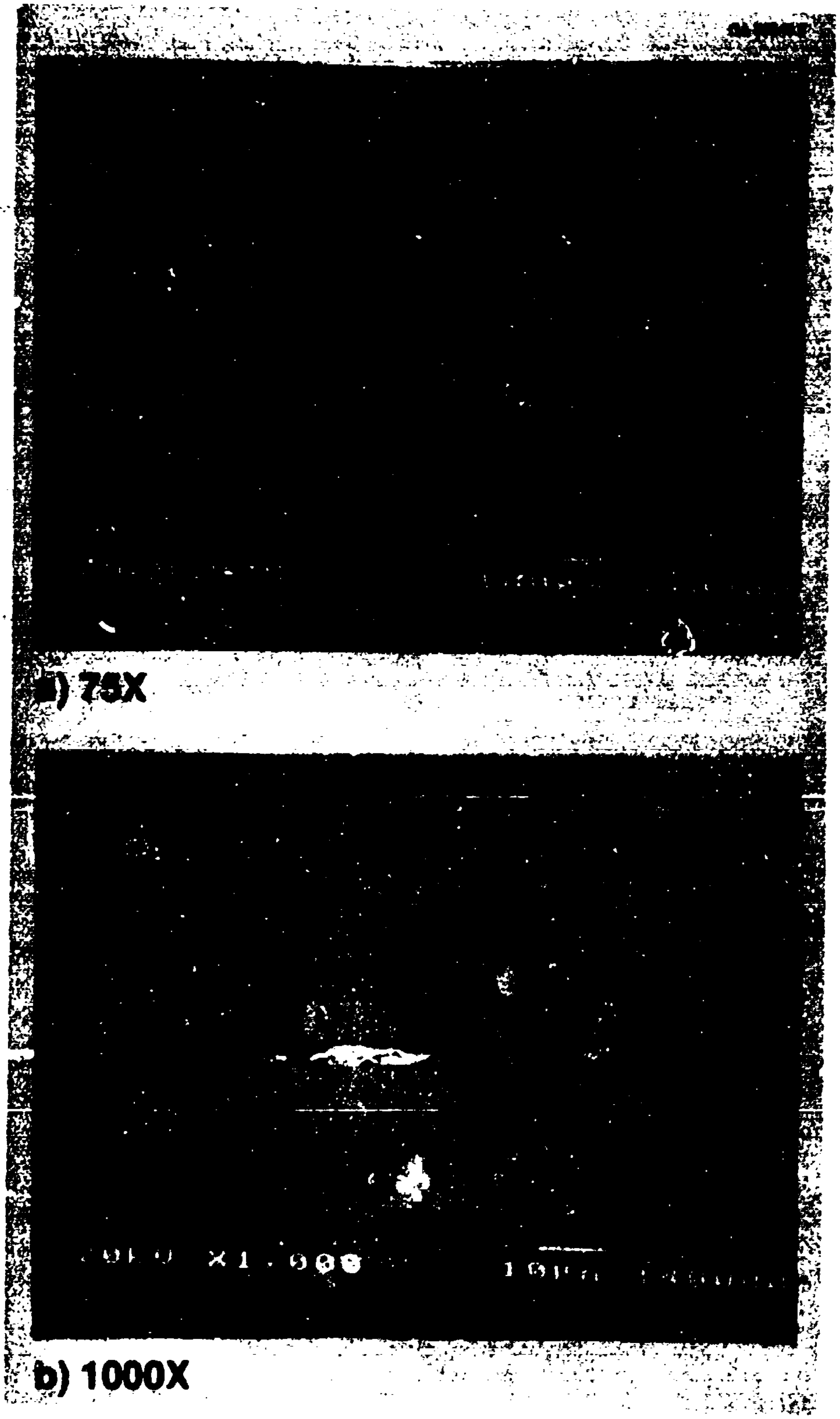


Figure 3.25 PMB Treated 0.050 in. Anodized 2024-T3 Sheet

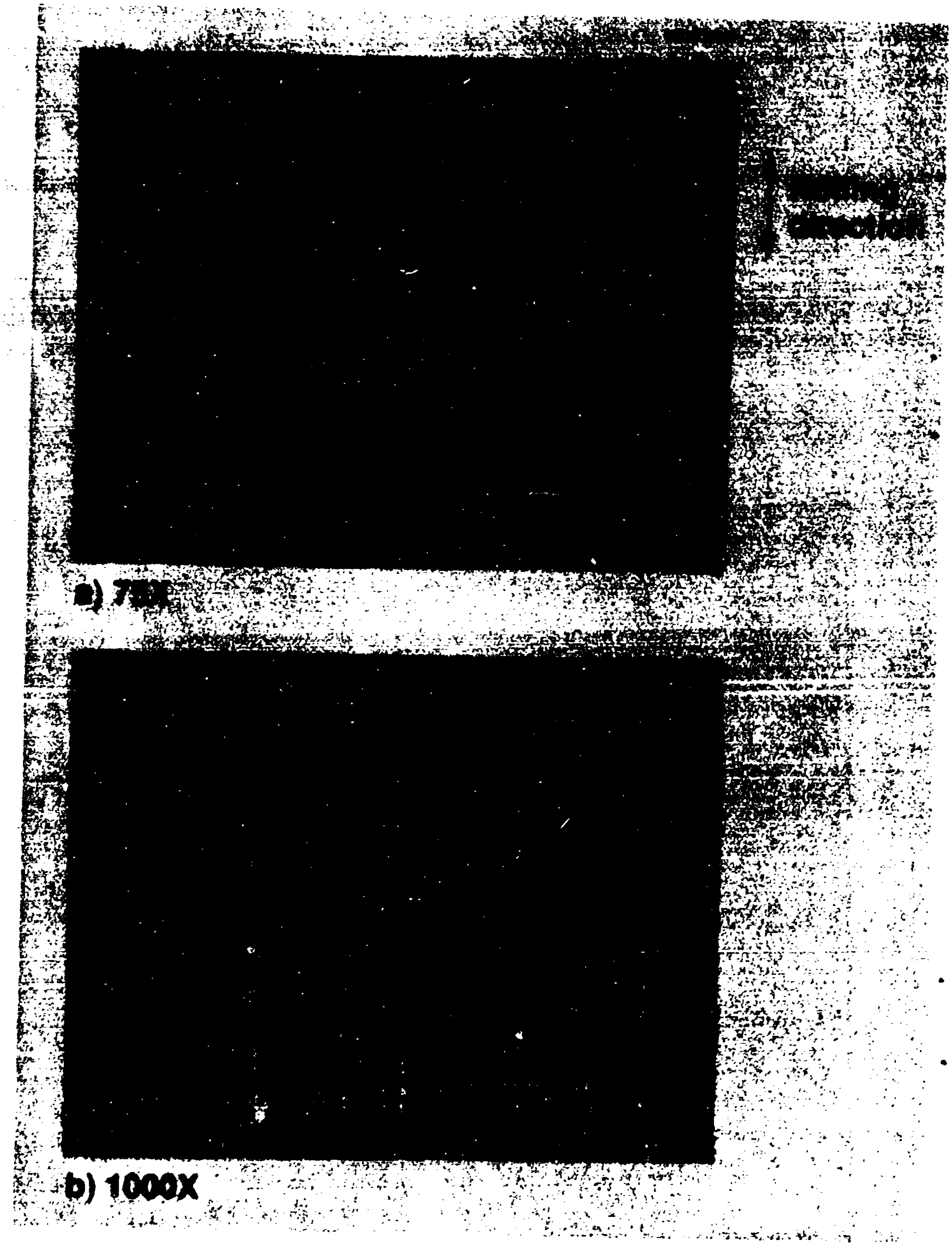


Figure 3.26 Untreated 0.032 in. Alclad 2024-T3 Sheet

Figure 3.27 PMB Treated 0.032 in. Alclad 2024-T3 Sheet

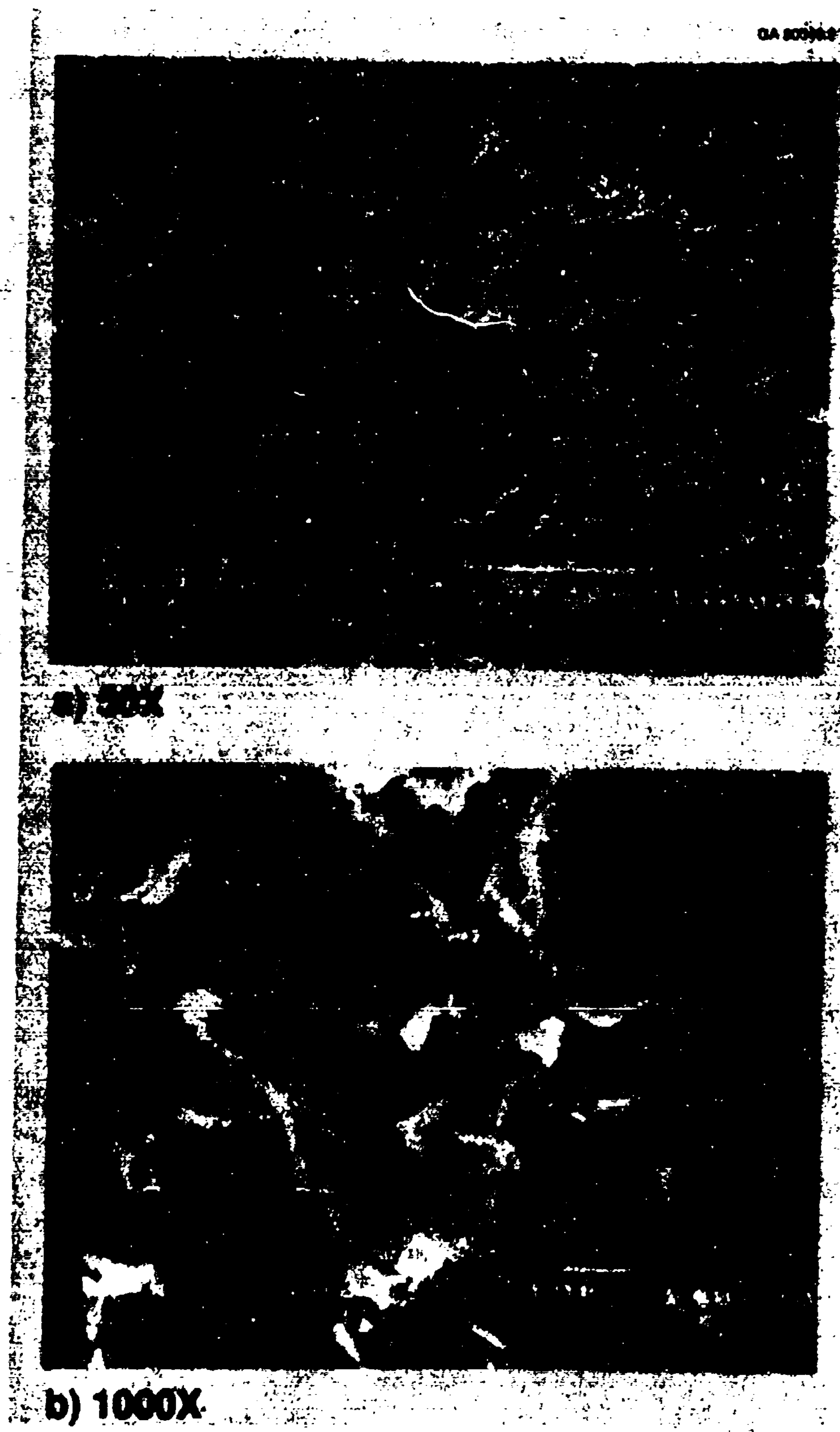


Figure 3.28 PMB Treated 0.040 in. Alclad 2(24-T3 Sheet

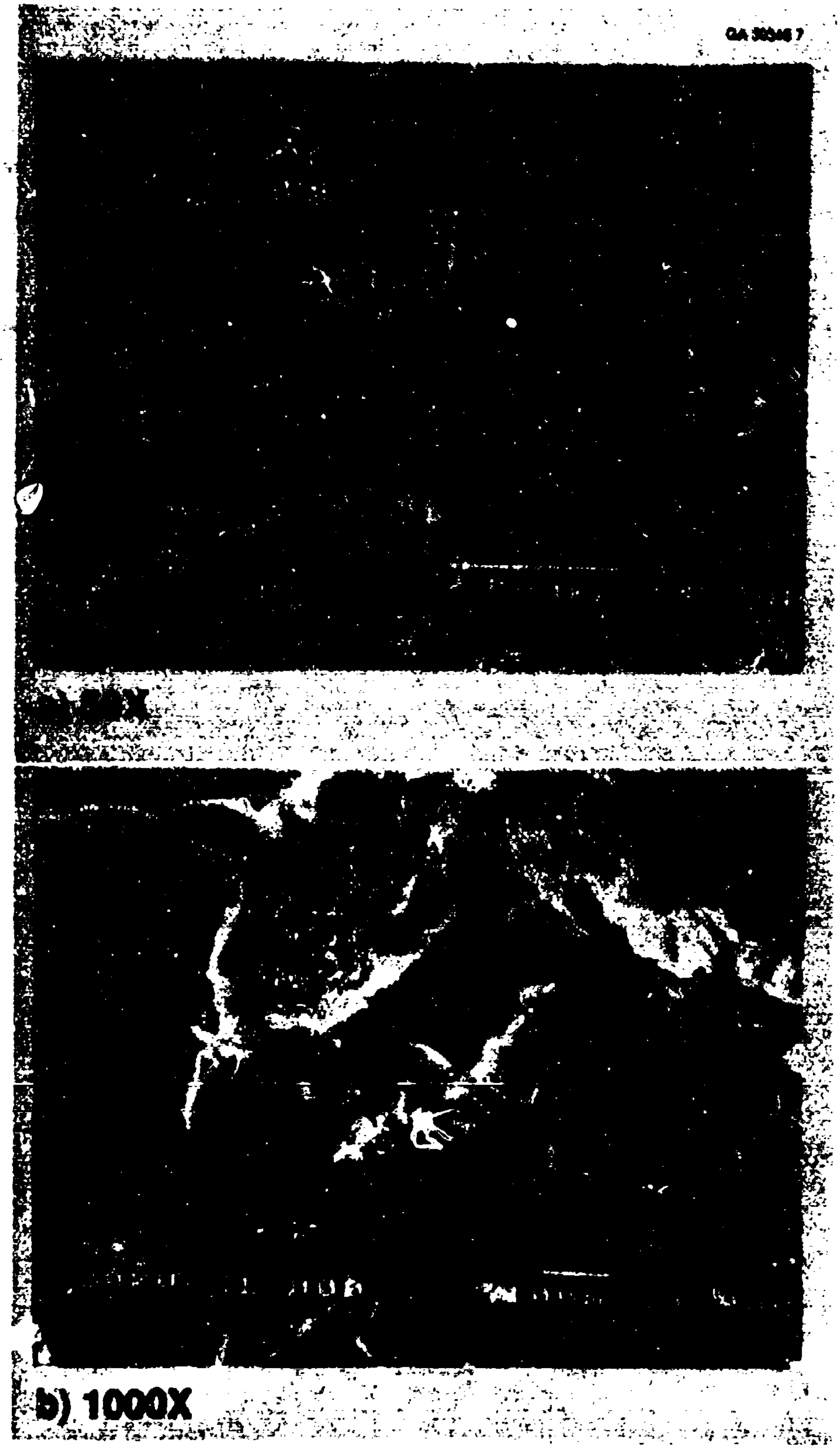


Figure 3.29 PMB Treated 0.050 in. Alclad 2024-T3 Sheet

Cross-sectional SEM photographs also depict the contrasting surface effect of the plastic media blast on the anodized and alclad aluminum. Figures 3.30 to 3.31 show sectional views of the unblasted and blasted anodized material and confirm that the anodized coating remained relatively intact. Figures 3.32 to 3.33 show sectional views of the unblasted and blasted alclad aluminum and demonstrate the pitting of the soft clad layer that took place as a result of the blast treatments.

SEM photographs were also taken of the fracture surface of blasted alclad specimens to investigate the apparent trailing of crack growth on the blasted side behind that of the unblasted side (Figures 3.34 and 3.35). Increased magnification views, shown in figure 3.36, confirm that the crack front does slope in the blasted specimen. This confirms the tests observations and can be attributed to increased tensile residual stresses on the blasted surface.

3.6 SUPPLEMENTARY DATA

During the course of the technical search a series of Almen strip arc height test data was collected and provided by MBB using the thicknesses and surface treatments being considered in this investigation. This data is presented for comparison purposes to contrast with the Almen arc height data presented in section 3.2. The arc height data in section 3.2 was obtained using both conservative and very aggressive parameters and, as already observed, exceeded the acceptable arc height of 0.006 inch as specified by industry (table 1.2).

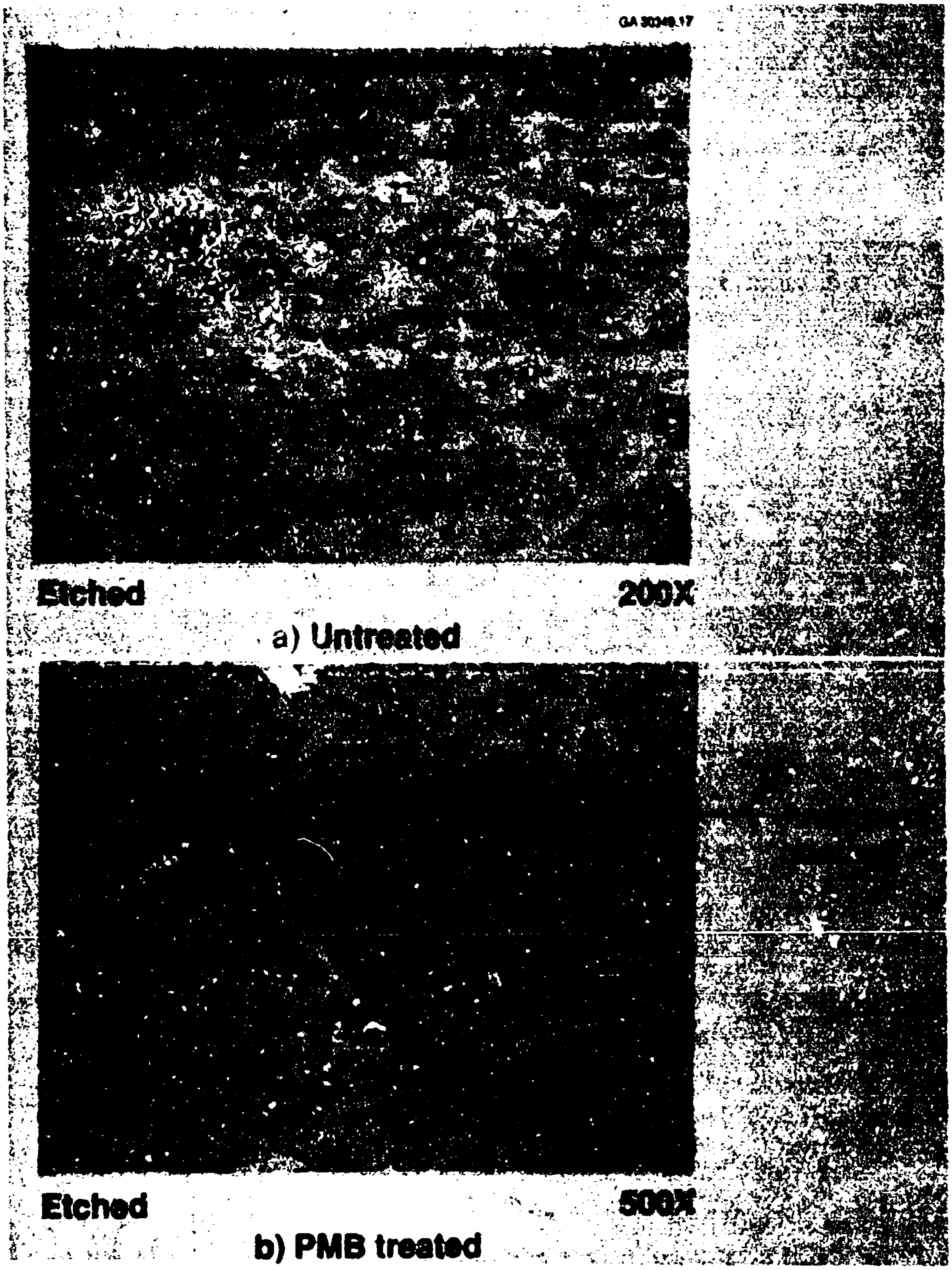


Figure 3.30 Sections Through 0.032 in. Anodized 2024-T3 Sheet

Etched

a) 0.040 in. anodized 2024-T3

Etched

b) 0.050 in. anodized 2024-T3

Figure 3.31 Sections Through PMB Treated Sheet

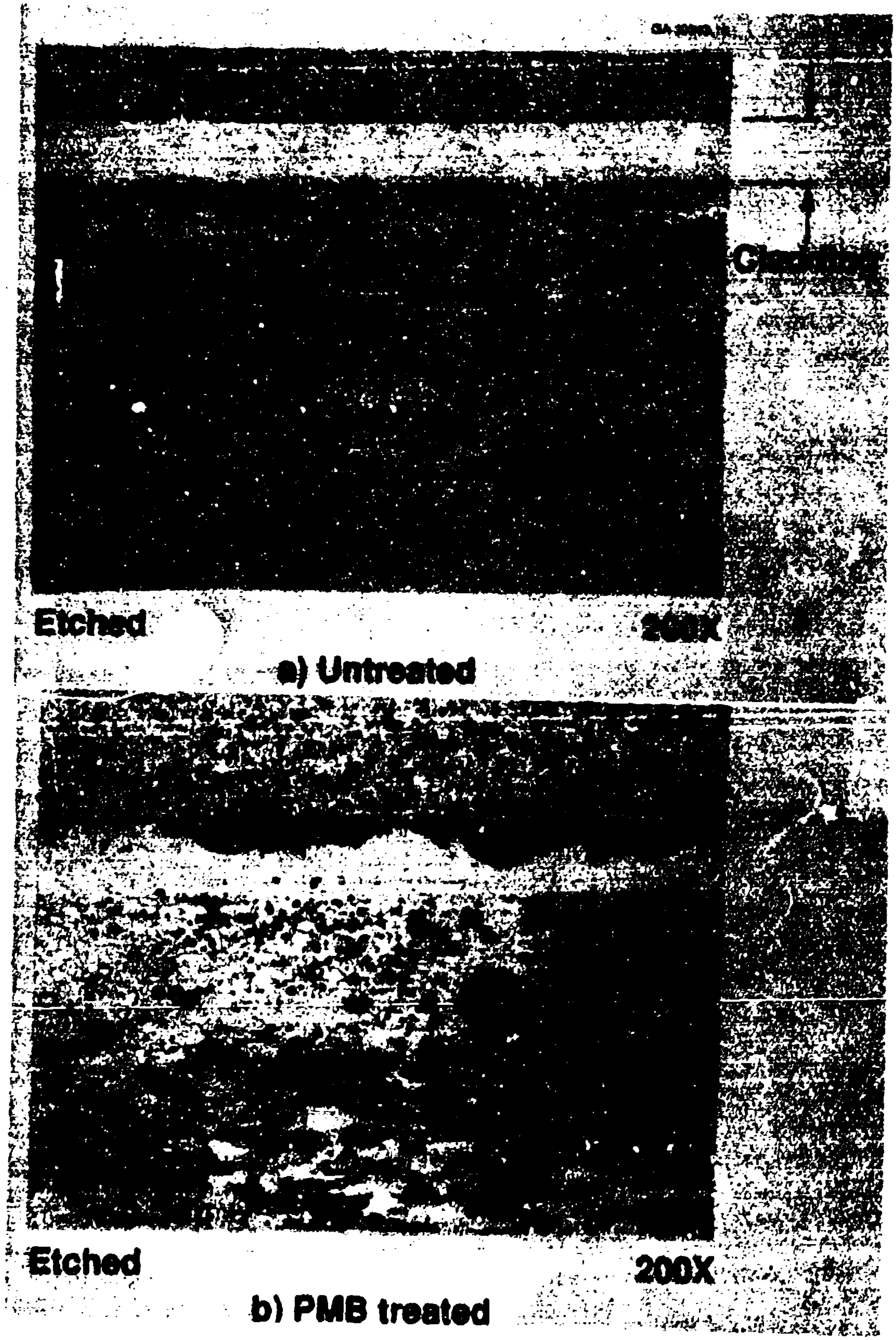
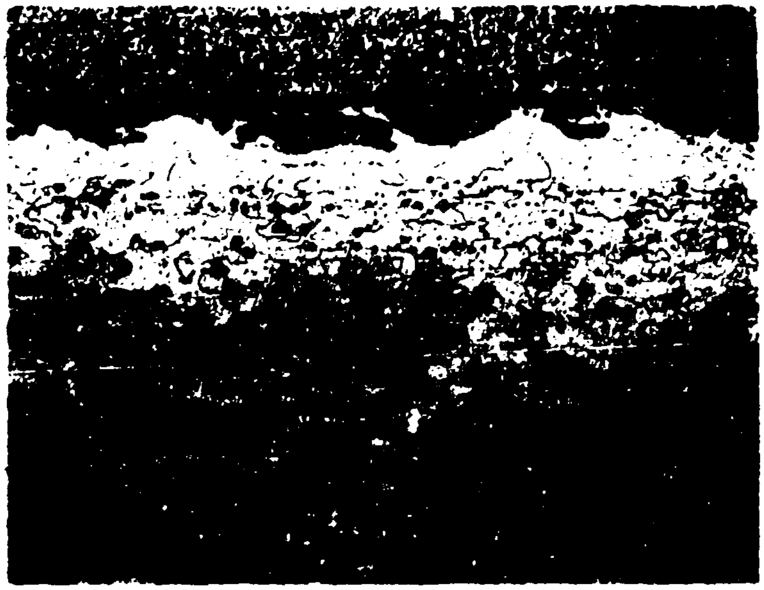


Figure 3.32 Sections Through 0.032 in. Alclad 2024-T3 Sheet

Etched 200X

a) 0.040 in. Alclad 2024-T3



Etched 200X

b) 0.050 in. Alclad 2024-T3

Figure 3.33 Sections Through PMB Treated Sheet

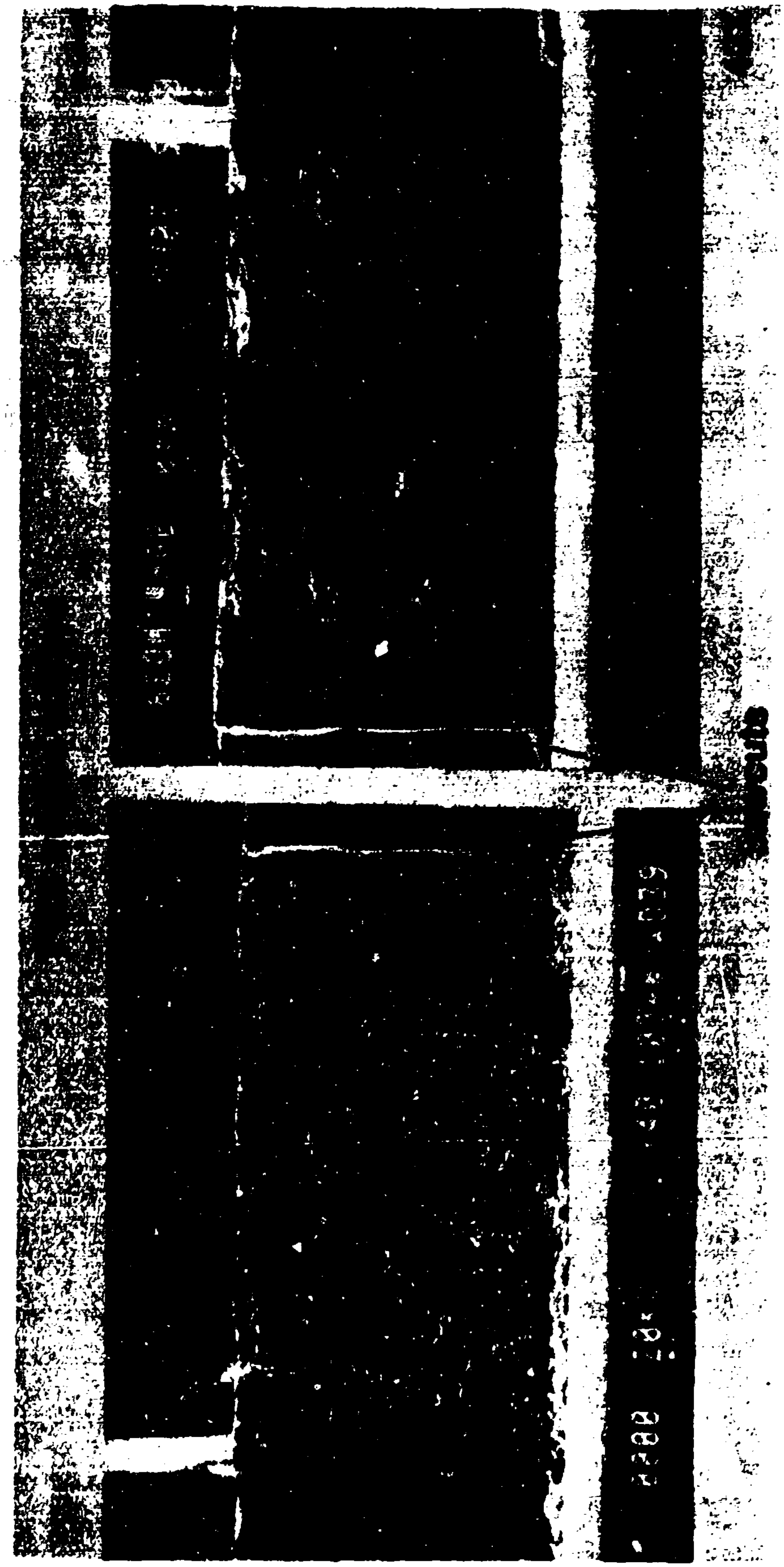


Figure 3.34 Fracture Surface of PMB Treated Specimen 0.032 in. Alclad 2024-T3 Sheet

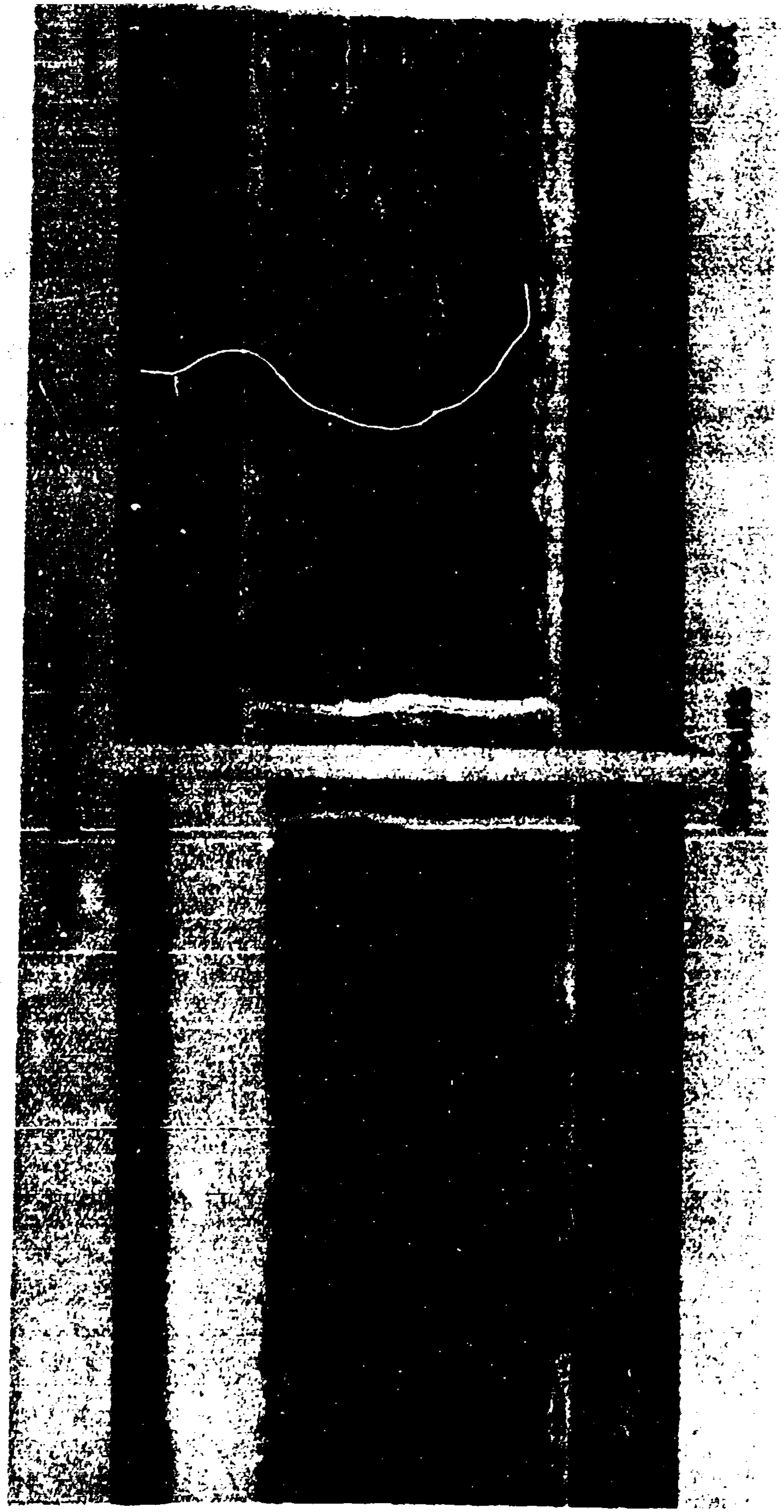


Figure 3.35 Fracture Surface of PMB Treated Specimen 0.050 in Alclad 2024-T3 Sheet

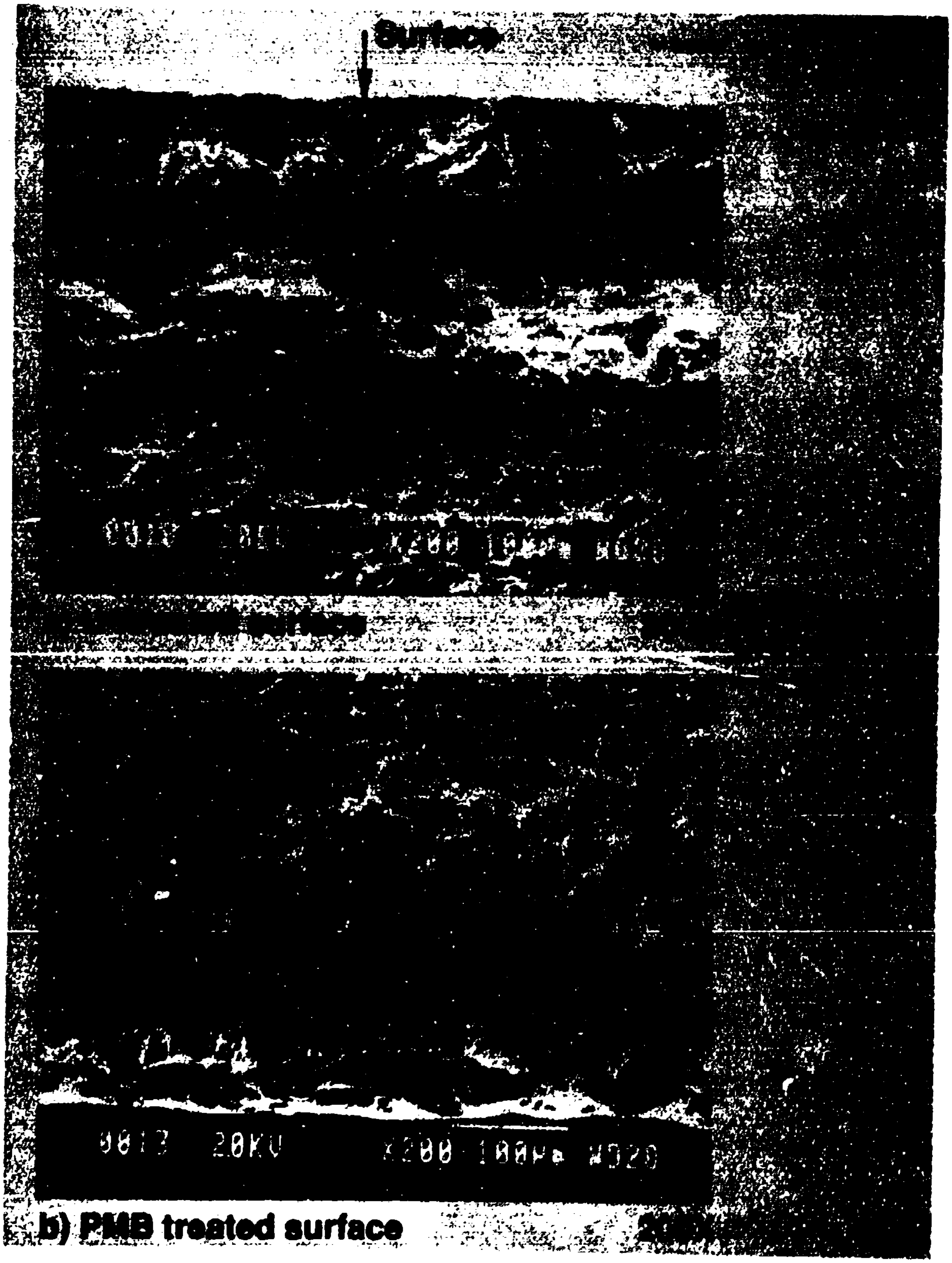


Figure 3.36 Fracture Surface Areas 1/2 inch from Hole, 0.050 in. Alclad 2024-T3 Sheet

Important distinctions must be made when comparing the MBB arc height data with that in section 3.2. Both plastic media blasting operations were performed using nozzle systems, however the blast equipment manufacturers were different, manual versus automated. Also, the blast pressures and impingement angles were different than those used to produce the arc heights presented in section 3.2. Table 3.9 shows the blast parameters that were reported for the MBB arc height data. A maximum dwell time of 3 seconds was observed for all specimens. Note that a different blast pressure was used for each material thickness; that for the 0.032 inch thickness was lower at 26.1 psi. Additionally, the aggressive Type II media, used to obtain the arc heights in section 3.2, was also used for the MBB tests. Table 3.10 presents the arc height values that were obtained using these blast parameters.

Table 3.9 MBB Almen Strip Test Blast Specifications

Blast Parameter	Specified Value	
	0.032 inch thickness	0.063 inch thickness
Media Type	Polyplus, size 30/40	Polyplus, size 30/40
Nozzle Pressure	26.1 psi	35 psi
Distance	11.8 inches	11.8 inches
Nozzle Diameter	-	-
Media Flowrate	529 lb/hr	728 lbs/hr
Impingement Angle	20-30 degrees	20-30 degrees
Number of Blast Cycles	4 (1 initial stripping, then 3 subsequent blasting)	4 (1 initial stripping, then 3 subsequent blasting)

Table 3.10 MBB Almen Strip Test Result Summary - Average Arc Heights

Blast Cycle	Anodized, Thickness (inches)		Alclad, Thickness (inches)	
	.032 anod	.063 anod	.032 clad	.063 clad
1	0.0009646	0.0013583	0.0004331	0.0009646
2	0.0012008	0.0016929	0.0004724	0.0009646
3	0.0015945	0.0016929	0.0006102	0.0009843
4	0.0019488	0.0016929	0.0006693	0.0009843
5	0.0020866	0.0016929	0.0006693	0.0009843
6	0.0020866	0.0016929	0.0006890	0.0009843

Note: Arc heights given in inches.

Figure 3.9 shows the saturation curve for the 0.032 inch anodized and 0.032 inch alclad average arc heights relative to the specified arc height of 0.006 inch. It can be seen from this figure that the saturation curves for both surface treatments become asymptotic at approximately 33 percent of the specified value. The same trend can be seen in figure 3.10 which presents saturation curves for 0.063 inch anodized and 0.063 inch alclad aluminum.

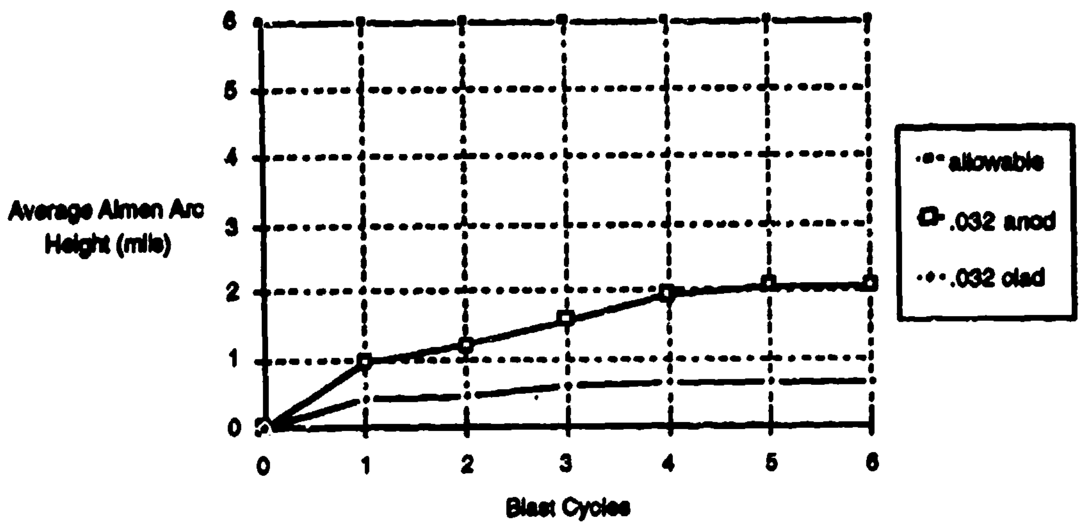


Figure 3.37 MBB Average Almen Strip Arc Heights, 26 psi on 2024-T3 0.032 Anodized and 0.032 Alclad Aluminum

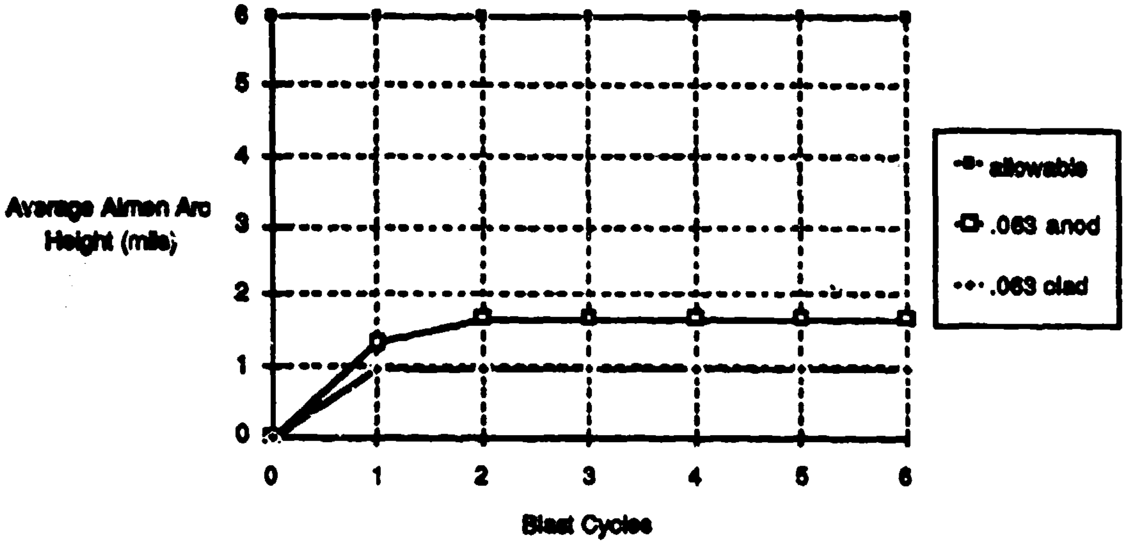


Figure 3.38 MBB Average Almen Strip Arc Heights, 36 psi on 2024-T3 0.063 Anodized and 0.063 Alclad Aluminum

In comparing these MBB saturation curves with those presented in section 3.2 several things can be noted:

- Saturation curves for anodized material were consistently higher than those for alclad material in both sets of data.
- Arc height values for 0.032 inch thick materials were consistently higher for those in the section 3.2 data set than those in the MBB data set.

In all, 10 specimens were tested for each thickness and surface treatment for a total of 40 Almen strips in the MBB data set.

4. CONCLUSIONS

The potential damage that can be caused by plastic media blasting is of two main types: residual tensile stress and surface flaws. These types of damage can affect and/or increase the fatigue crack growth rate.

The fatigue crack growth rate found in the 2024-T3 anodized aluminum showed no significant change when PMB blasted. After analyzing the Almen strip arc height data, it was recognized that the crack growth experienced retardation due to the cold working effect induced by this stripping process.

The fatigue crack propagation rates, after PMB treated, were also determined for the thin alclad 2024-T3 sheet specimens, and they ranged from 1.05 to 4.09 times those obtained for the untreated samples at intermediate stress intensity range (refer to Table 3.6). According to fracture mechanic practices, an increase of more than two times the control specimen's crack growth rate is considered to be significant and will affect the service life of the material. Apparently, clad surfaces act to cushion the blast for the metal alloy, therefore, the cold working effect is not present or not sufficient to retard crack growth. The Almen data showed that 2024-T3 alclad aluminum experienced lower residual stress levels than the anodized counterpart when both were subjected to the same blast intensity. The crack size significantly increased at a lower life cycle (more than 50 percent reduction in some instances). The increased crack growth rate found in the alclad specimens for all three thicknesses can be attributed to surface damage including thickness reduction caused by the evaluated process and selected parameters.

Plastic media particle contamination can cause surface flaws. Increases in fatigue crack propagation rates have been observed because of these contaminant-induced surface flaws. Dense particle contaminant thresholds recommended by user specifications and accepted as standard practice is to have a contamination level of less than 0.03 percent.

Aggressive use of plastic media blasting (Type II media, 30/40 mesh at 35 psi) can damage alclad surface, thus reducing its corrosion protection capabilities. The surface layer of 2024-T3 alclad aluminum was damaged by the aggressive blast procedures as indicated by surface roughness measurements and Scanning Electron Microscope (SEM) photographs.

Strict control and repeatability are required for plastic media blasting parameters. The Messerschmitt-Bolkow-Blohm (MBB) arc height data demonstrate that acceptable arc heights can be obtained

reproducibly if the equipment is precisely calibrated controlled, and maintained with parameter values appropriate for the substrate being stripped.

Almen strips provide a means of monitoring the effects of plastic media blasting. Analytical methods that correlate Almen strip arc heights with the blast-induced residual stress can support assessments of potential substrate damage, including increases in the crack growth rate. Almen strip tests can not, however, be used as an indicator of surface flaw damage.

When plastic media blasting is properly employed and saturation is reached at a safe stress level, the maximum number of strippings that may be performed is unlimited.

Alternative paint stripping methods to plastic media blasting currently exist and others are being developed that show potential as viable techniques in terms of aircraft safety, positive environmental impact, and economics.

5. REFERENCES

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10. AIPS 02-100, Airbus Industrie, January 1990.

11. "Organic Finish System Removal," Secticn II, TO 1-1-8, U.S. Air Force.

12. Svejkovsky, Donald L., "Plastic Media Blasting Project 8TS084S," Engineering Laboratory, Oklahoma City Air Logistics Center, June 1989.

13. Flock, Gretchen, "Reducing Risk in Paint Stripping - Proceedings of an International Conference," Office of Toxic Substances, Environmental Protection Agency, February 1991.

14. Pauli, Robert, and Drake , Cameron, "Dry Stripping -- Seven Years Later," Pauli & Griffin Company, May 1992.

APPENDIX A - TECHNICAL SEARCH RESULTS

The following list is a bibliography of reports, papers, and other documents that were obtained and reviewed during the technical search. This listing is intended to serve as a source guide to aid future researchers.

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Gemmell, Vanessa, and Smith, Brian, "VOC Reduction: Solvent Cleaning and Paint Stripping," Society of Automotive Engineers (SAE) paper 900958, April 1990.

Kozol, J., Thoman, S. J., and Clark, K., "The Effects of Plastic Media Blasting Paint Removal on the Microstructure of Graphite/Epoxy Composite Materials," Naval Air Development Center, October 1988.

"Organic Finish System Removal," Section II, TO 1-1-8, U.S. Air Force.

"Paint Stripping," Minutes of International Air Transport Association (IATA) Taskforce Meeting, December 1990.

Pauli, Robert A., and Drake, Cameron, "Dry Stripping--Seven Years Later," Pauli & Griffin Company, May 1992.

Pauli, Robert A., and Owens, Charles E., "Plastic Media Training Requirements and Supporting Technical Data," Society of Automotive Engineers (SAE) paper 880865, April 1988.

"Plastic Bead Blast Materials Characterization Study - Separator Study," Battelle Memorial Institute, March 1987.

Plastic Media Blasting for the Aircraft Industry: A Technical Guide," E.I. DuPont de Nemours and Company, 1990.

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Radonich, B., and Wells, M., "Evaluation of Plastic Media Blasting Equipment," Engineering Management Concepts, April 1989.

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Then, M.J., "The Future of Aircraft Paint Removal Methods," Masters Thesis, Air Force Institute of Technology, September 1989.

Thoman, S. J., and Kozol, J., "The Effects of Plastic Media Blasting Paint Removal on the Mechanical Properties of Graphite/Epoxy Composite Materials," Naval Air Development Center, April 1989.

APPENDIX B - PAINTING AND BLASTING TEST PROCEDURES

TEST PLAN - Aero-Tech Coatings Removal, Inc

Paint Specifications

1. Clean metal surface to remove surface contaminants.
2. Abrade metal surface with water and abrasive nylon web pads to obtain a water-break-free surface.
3. While still wet, surface treat abraded side of coupon with MC coating material meeting MIL-C-81706 to produce a coating conforming to MIL-C-5541.
4. Within 4 hours after surface treating, mix and apply an epoxy-polyamide primer conforming to MIL-P-23377. Apply primer to obtain a smooth and even dry film thickness of 1.0 to 1.3 mils.
5. Allow primer to air dry 2 to 24 hours before applying an aliphatic polyurethane topcoat (color optional) conforming to MIL-C-83286. Apply coating to a dry film thickness of 1.8 to 2.4 mils of topcoat.
6. The coated metal (one side only) should be allowed to air dry one week, then oven cure for 100 hours at 210_ F ±5 F.

Note: These paint specifications follow McDonnell Douglas requirements CSD #4.

APPENDIX B - PAINTING AND BLASTING TEST PROCEDURES;

TEST PLAN - Aero-Tech Coatings Removal, Inc

Blast Specifications

Media

Type: Type II
Mesh size: 30/40
Purity: 99.95 % strictly controlled during blasting

Blasting Parameters

Pressure: 35 psi
Distance: 12 inches
Nozzle: 0.5 inch diameter, straight nozzle if possible
Flow rate: 870 lb/hr
Impingement angle: 90 degrees
Number of strippings: 4 (1 initial stripping, then 3 subsequent blasting)

Substrate

Materials: To be supplied by Alcoa
2024-T3 aluminum
0.032, 0.040, 0.050 inch alclad
0.032, 0.040, 0.050 inch anodized
Quantity: 6 panels total, one of each thickness for both surface treatments
Size: each panel = 14x14 in^2

Measurements To Be Taken

Stripping rate
Dwell time
Breakdown rate
Almen strip tests: 5 Almen strips for each panel blasted

-arc height measurements to be taken after each blasting
-total of 30 Almen strips

Table B.1 Blast Parameters

<u>BLAST PARAMETERS:</u>	35-psi nozzle 12-inch nozzle distance from substrate 90 degree nozzle angle (from horizontal) 1/2-inch diameter straight nozzle size 900 lb/hr media flow rate

Table B.2 Media Type

<u>MEDIA TYPE:</u>	Type II (Urea Formaldehyde)	
	Grade:	A
	Mesh Size:	30-40
	Ship date:	March 18, 1991
	Lot Number:	43
	Manufacture:	Composition Materials, Inc. 1375 Kings Highway East Fairfield, CT 06430

Table B.3 Paint Stripping Rate and Dwell Time, 2024-T3 Anodized Aluminum

Test Panel Number	Paint Removal Area, ft^2	Paint Removal Time, sec	Paint Removal Rate, ft^2/min	Dwell Time, sec/ft^2
AN32-1	1.36	30	2.72	0.37
AN40-1	1.36	26	3.14	0.32
AN50-1	1.36	26	3.14	0.32
		Average	3.00	0.34

Table B.4 Paint Stripping Rate and Dwell Time, 2024-T3 Alclad Aluminum

Test Panel Number	Paint Removal Area, ft^2	Paint Removal Time, sec	Paint Removal Rate, ft^2/min	Dwell Time sec/ft^2
AL32-1	1.36	37	2.21	0.45
AL40-1	1.36	47	1.74	0.57
AL50-1	1.36	54	1.51	0.66
		Average	1.82	0.56

Table B.5 Plastic Media Particle Size Distribution

VIRGIN MEDIA PARTICLE SIZE DISTRIBUTION

Media Type:	Type II (Urea Formaldehyde)
Grade:	A
Mesh Size:	30-40
Ship date:	March 18, 1991
Lot Number:	43
Manufacture:	Composition Materials, Inc. 1375 Kings Highway East Fairfield, CT 06430

WEIGHT, gms

Sieve Size	Pan With Media	Paint Removal Time,sec	Empty Sieve or Pan	Percent by Weight
12	440.0	440.0	0.0	0.0
16	435.9	435.9	0.0	0.0
20	398.9	398.9	0.0	0.0
30	404.3	393.0	11.3	11.2
40	446.0	377.6	68.4	68.0
60	376.8	355.9	20.9	20.8
80	347.4	347.4	0.0	0.0
PAN	372.0	372.0	0.0	0.0
		Total	100.6	100.0

Table B.6 Media Particle Size Distribution After 4 PMB Cycles

BLAST PARAMETERS: 35 psi nozzle pressure
12 inch nozzle distance from substrate
90 degree nozzle angle (from horizontal)
1/2 inch diameter straight nozzle
900 lb/hr media flow rate

WEIGHT, gms

Sieve Size	Pan With Media	Paint Removal Time,sec	Empty Sieve or Pan	Percent by Weight
12	440.0	440.0	00.0	00.0
16	435.9	435.9	00.0	00.0
20	398.9	398.9	00.0	00.0
30	394.0	393.0	01.0	01.0
40	394.7	377.6	17.1	17.1
60	394.2	355.9	38.3	38.3
80	366.2	347.4	18.8	18.8
PAN	396.7	372.0	24.7	24.7
		Total	99.9	99.9

Table B.7 Media Breakdown Rate Calculation
(Product retained on 30 mesh sieve)

$$\text{Consumption} = \frac{\text{Virgin media weight} - \text{4 PMB cycle media weight}}{\text{Virgin media weight} \times \text{4 PMB cycles}}$$

$$= \frac{11.3 + 68.4 - 1.0 - 17.2}{(11.3 + 68.4) \times 4)} \quad X \quad 100$$

$$= 19.3\ \%/\text{cycle}$$

Figure B.1 Plastic Media Blast System with Operator

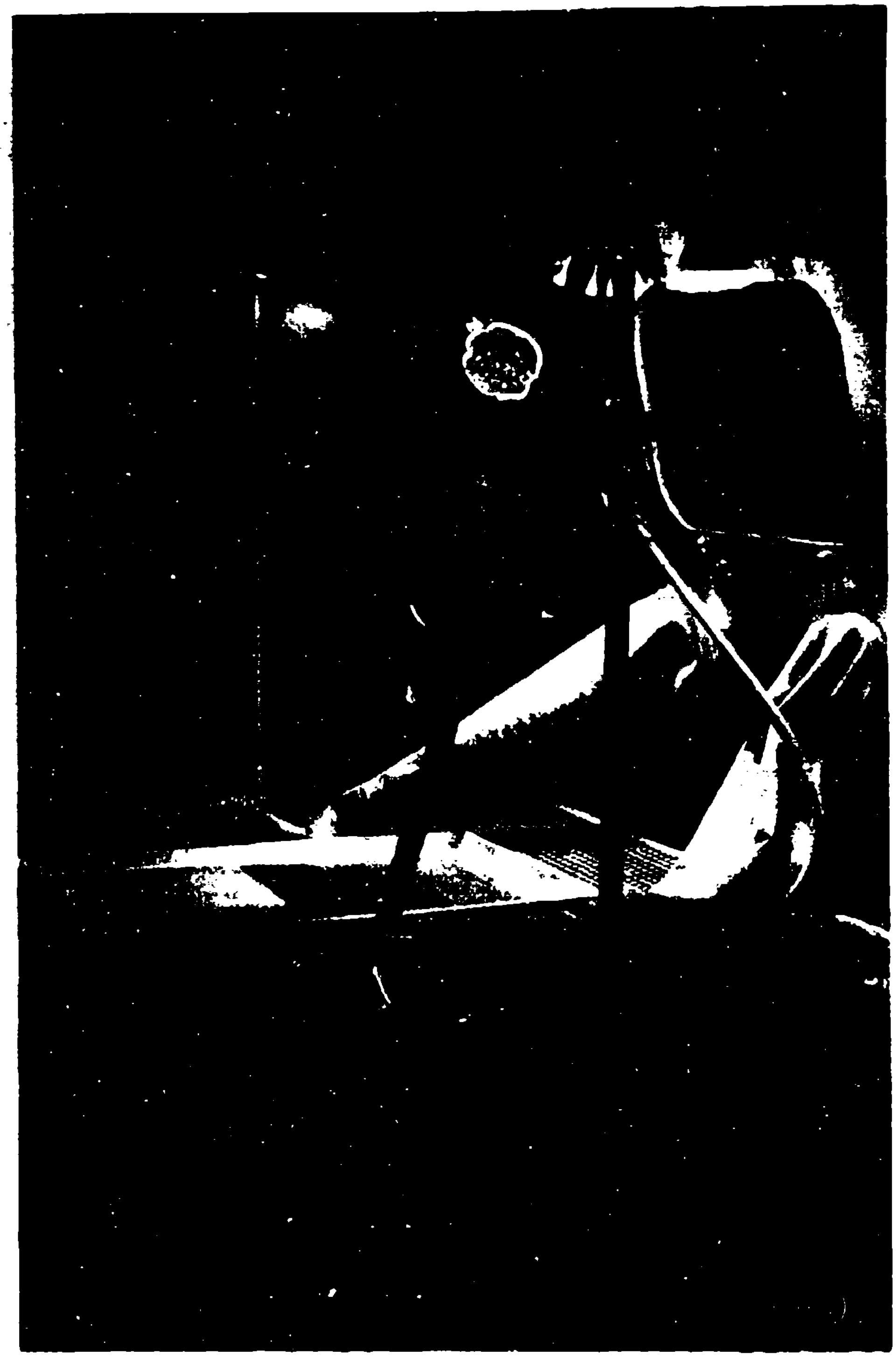

Figure B.2 Plastic Media Blast System Interior with Nozzle Restraint Fixture and Specimen

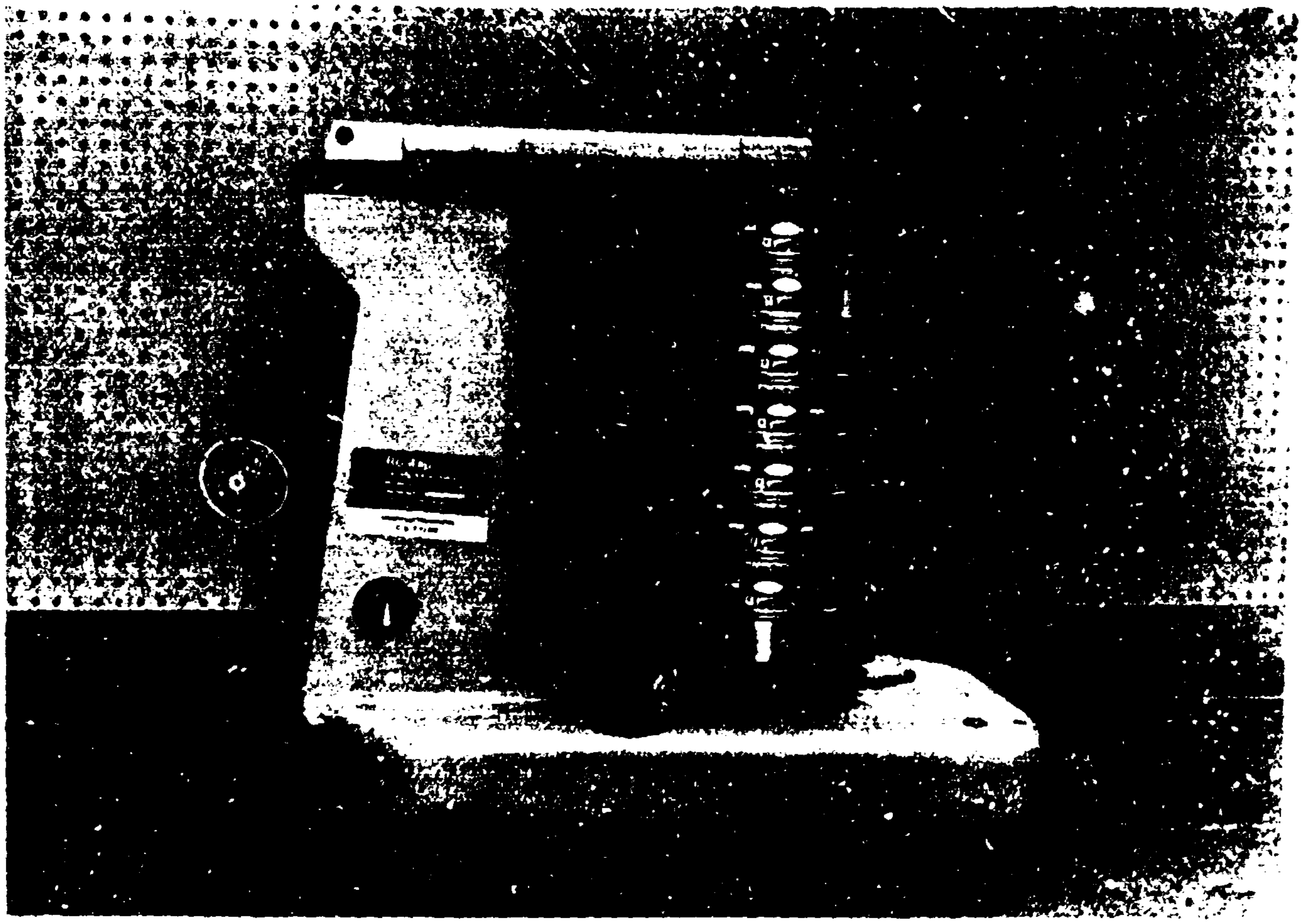

Figure B.3 Tyler-Ro-Tap Sieve Test Equipment

APPENDIX C - ALMEN STRIP TESTS

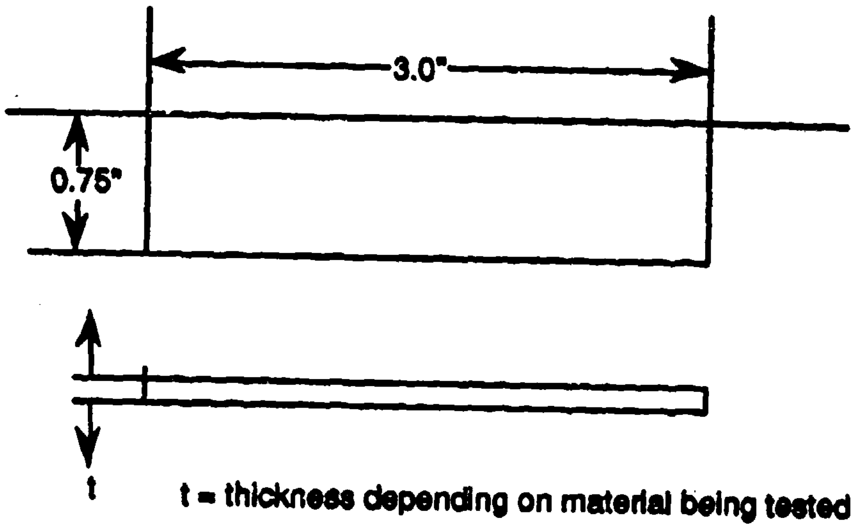

Figure C.1 Almen Strip Specified Dimensions

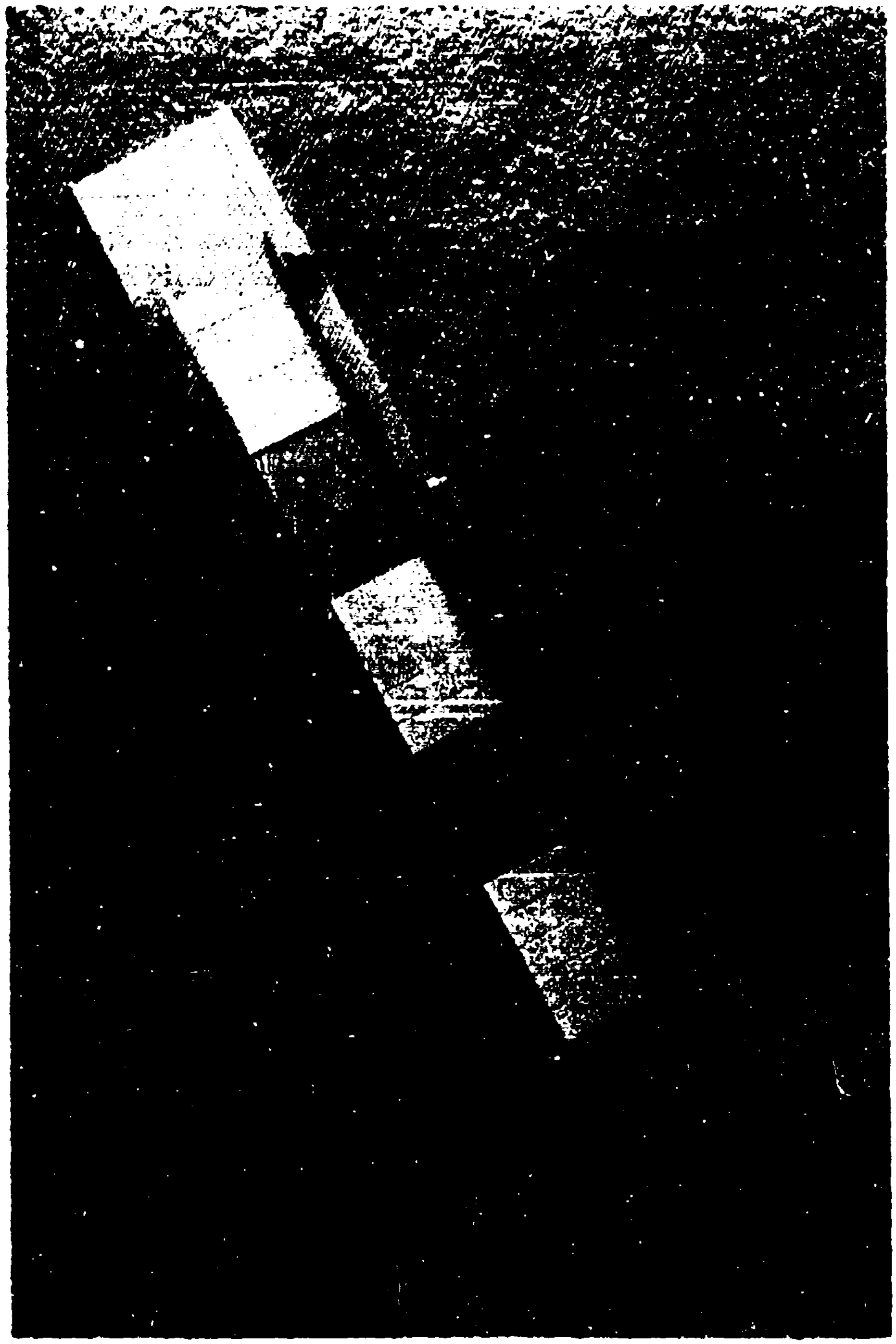

Figure C.2 Almen Strip Test Fixture and Almen Arc Height Gauge

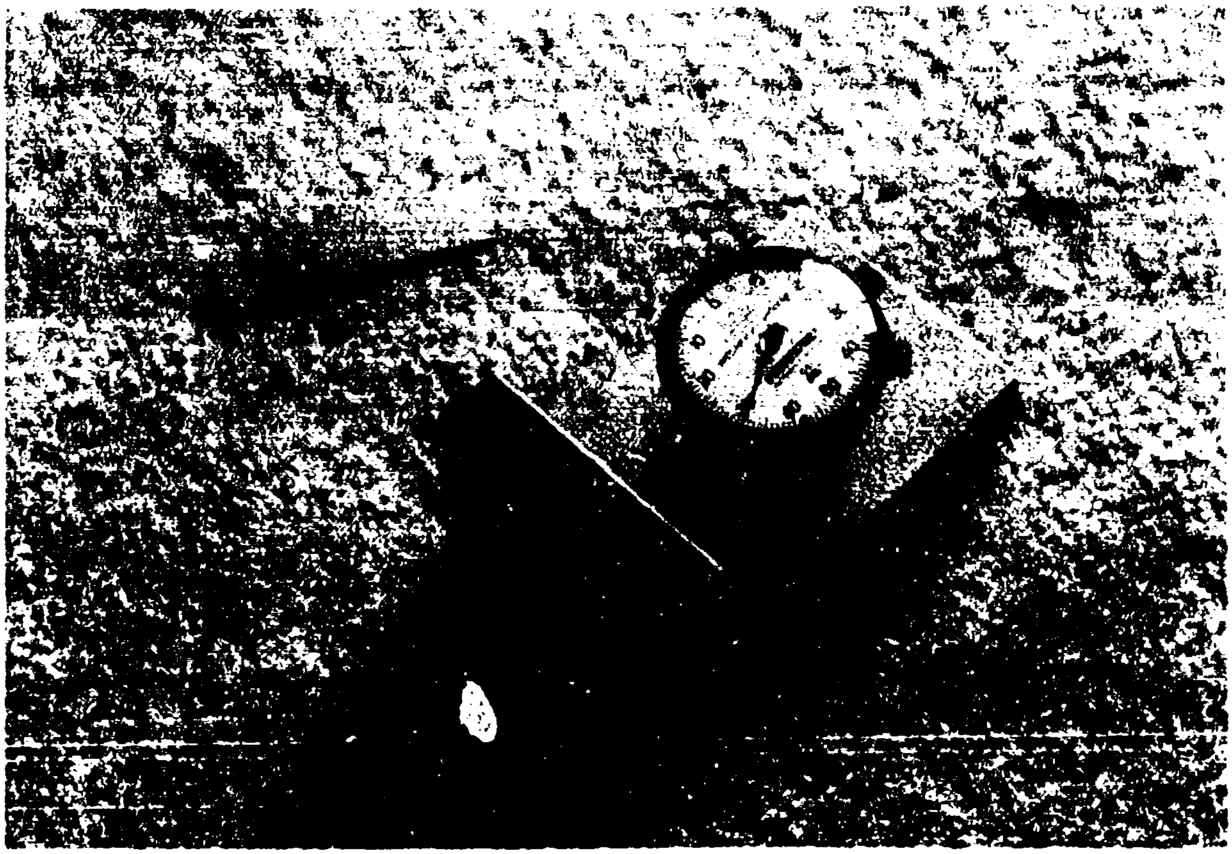

Figure C.3 Almen Gauge Test Fixture

APPENDIX D - FATIGUE CRACK PROPAGATION TEST PROCEDURES

TEST PLAN - Performed by Alcoa Laboratories
Crack Propagation Test Specifications

Baseline		Painted
As-Received metal		Painted, aged, stripped, then blasted three more times
0.032"		
alclad	X	X
anodized	X	X
0.040"		
alclad	X	X
anodized	X	X
0.050"		
alclad	X	X
anodized	X	X

In addition: 4 duplicate tests will be performed, to be decided later.
Media Type: Type II

Fatigue Crack Propagation Tests:

Stress ratio R = 0.1
Maximum Load = 600 lb
Lower limit for crack growth 10^{-6} inch/cycle
Use same machine to perform all crack propagation tests to avoid calibration error

Additional Required Measurements:

Amount of cladding and anodizing lost during painting and stripping

Summary: A total of 16 fatigue crack propagation tests will be performed by Alcoa, according to the test plan above. The duplicate tests to be performed will be determined by Alcoa, Galaxy Scientific Corporation, and the FAA Technical Center based on the preliminary outcome of the first 12 tests. The painting and stripping of the panels will be performed according to the attached specifications 1 and 2 in Appendix B.

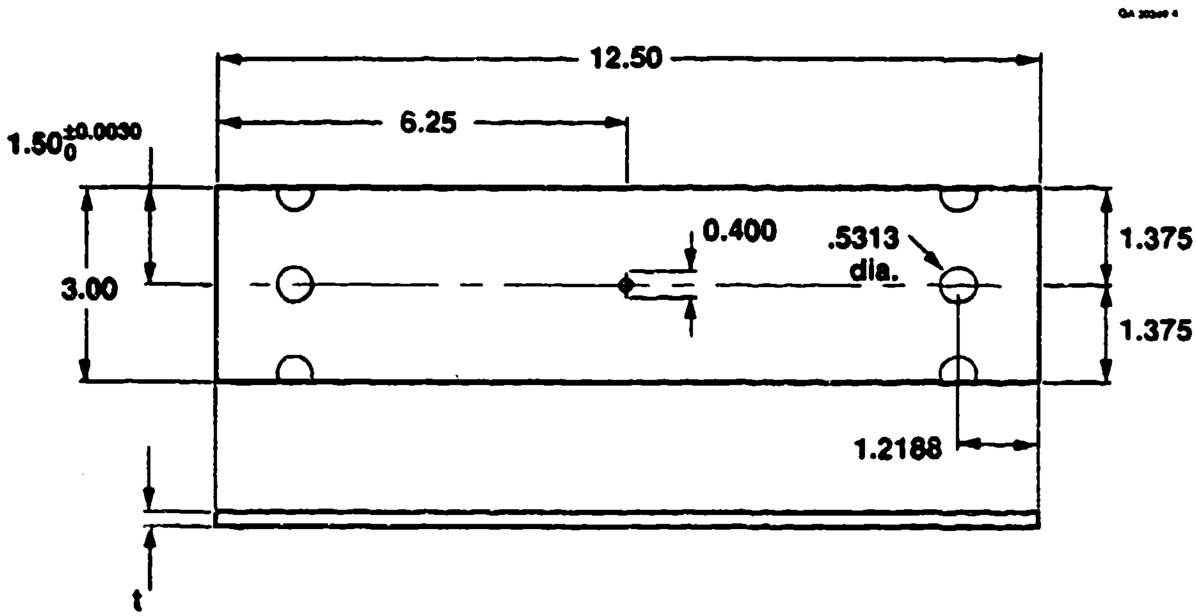

Figure D.1 Fatigue Crack Propagation Specimen Dimensions

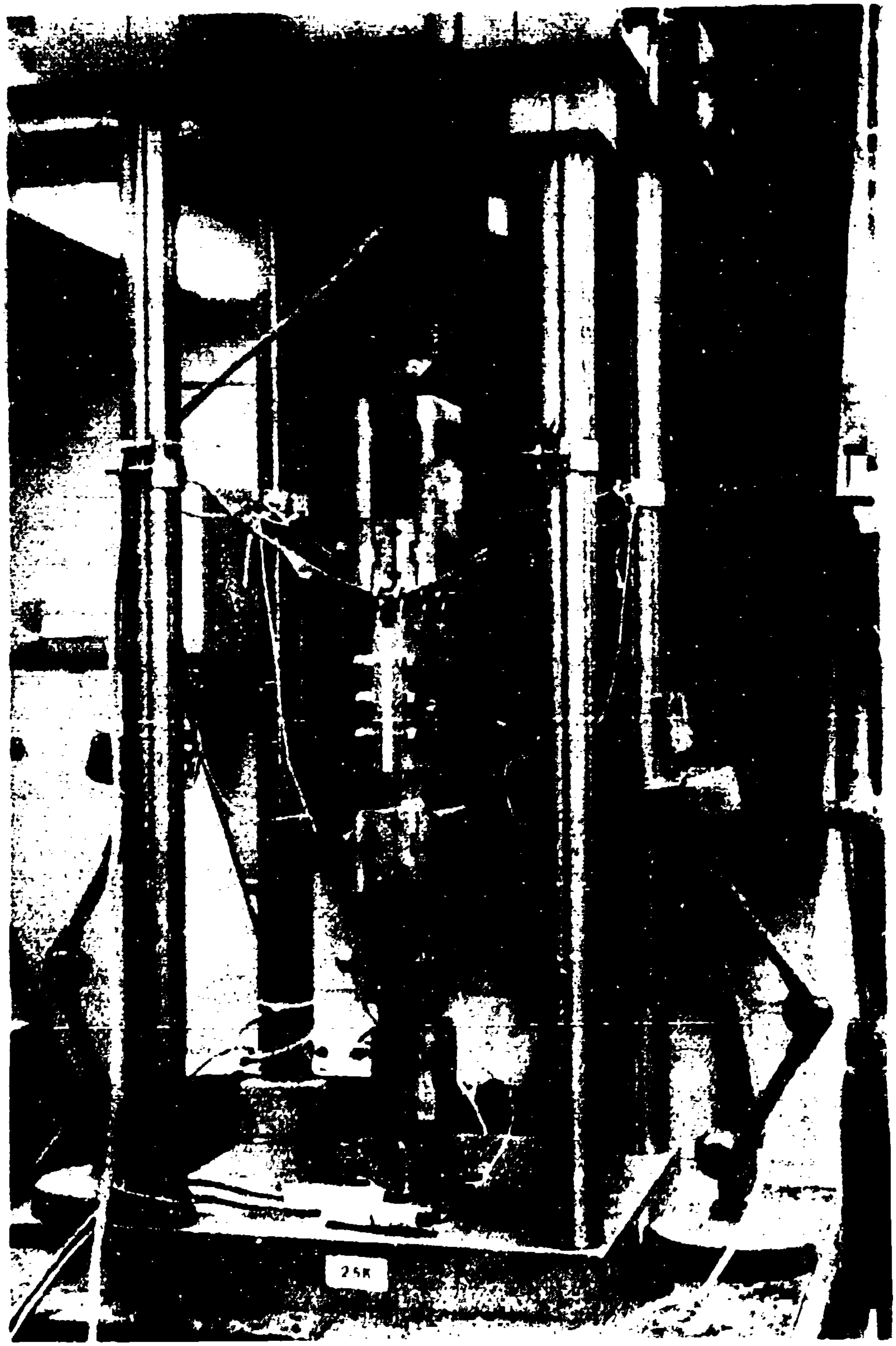

Figure D.2 Fatigue Crack Propagation Test Utilising Anti-Buckling Guides

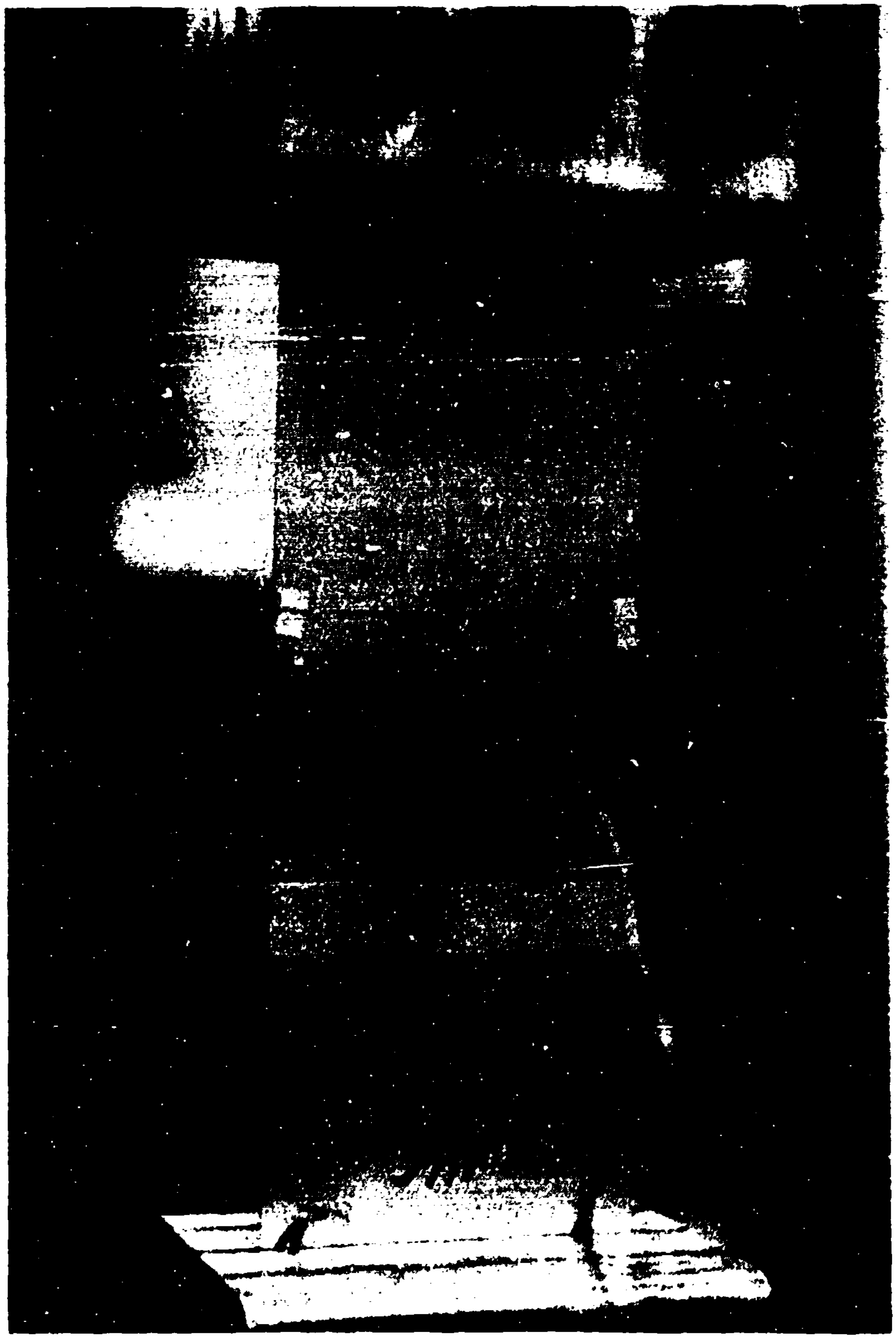

Figure D.3 Fatigue Crack Propagation Specimen in Grips

APPENDIX E

ALTERNATIVE PAINT STRIPPING METHODS-AN OVERVIEW

INTRODUCTION

In response to the challenge of safely and economically replacing methylene chloride paint strippers many alternative paint stripping methods are being developed. These methods each utilize a variety of paint removal mechanisms. Each method has advantages and disadvantages in effectiveness, substrate sensitivity, environmental cost, health cost, and economic cost. Comparisons can be difficult to make since there are a wide variety of parameters which must be considered. For example, one strip rate may be higher, but then this neglects multiple nozzles that may increase the lower rate for an equivalent cost. Additionally, the material/method with a lower strip rate may have a lower disposal cost than the faster material/method.

The objective of this section is to compare several alternative paint removal methods by using a common measure of performance. The alternative technologies considered in this section are: blasting with plastic media, wheat starch, sodium bicarbonate, carbon dioxide, and ice; non-methylene chloride solvents; thermal/optical paint removal with lasers and flashlamps; and a combined water and solvent method. These technologies are then evaluated on their performance in five areas:

1. paint stripping effectiveness
2. substrate damage
3. environmental impact
4. health impact
5. cost

ESTABLISHMENT OF COMPARISON CRITERIA

It was necessary to establish a common measure of performance so that a matrix comparison could be made in the five chosen areas. The common measure of performance chosen was the removal of an polyurethane aviation coating from a Boeing 747-400 transport aircraft with a surface area of 25000 square feet (reference 13, p.114). Because the method of applying the various paint removal methods differs, it was assumed for the purpose of this comparison that only one worker and/or delivery unit was performing the stripping operation.

DATA COLLECTION

To gather the necessary information uniformly and efficiently a survey sheet was developed. The purpose of this sheet was to obtain the specific numerical data necessary to prepare

Table E-1 Effectiveness of Alternative Aviation Paint Removal Methods for Standard Area

Paint Removal Method	Strip Rate	Strip Time (hrs)	Media/Solvent Consumption (pounds)	Geometry Limitations
Mechanical				
Plastic Media	3 ft2/min	139	83,400*	None
Wheat Starch	1.5 ft2/min	278	250,200*	None
Sodium Bicarbonate	2 ft2/min	208	99,840	None
Carbon Dioxide	0.067-0.167 ft2/min	2500	1,500,000	None
Ice	1.33-1.67 ft2/min	250	125,000	None
Thermal/Optical				
Lasers	4-5 ft2/min	83	Energy	None
Flashlamps	3 ft2/min	138	Energy	None
Solvent				
Non-methylene	1-3 hours	140	125 gallons	None
Chloride Based				
Other				
Combined Water	1-3 hrs (solvent)	232	125 galons (solvent)	None
and Solvent	108 ft2/hr (water)		136,138 gallons (water)	

*Note: Material passing through nozzle

quantitative cost and performance comparisons in the five evaluation areas. The summary sheet was sent to manufacturers, sales representatives, and end users of the products and systems being investigated. Appendix F contains a copy of this survey sheet. This information was supplemented by other data researched independently.

ANALYSIS

Paint Removal Effectiveness

The raw strip rate information gathered for the various paint removal methods was used to determine the time required to strip a given area of paint. As described in Table E-1, this given area was the surface area of a Boeing 747-400 transport aircraft, defined as having 25,000 square feet of surface area.

Table E-1 presents the overall comparison of paint removal effectiveness for the paint removal methods being examined. The following evaluations may be made:

- Lasers, though possessing the fastest strip rate, are still in the experimental stage.
- Plastic media, flashlamps, and the non-methylene chloride solvent all have comparable strip rates and rank next below lasers.
- Carbon Dioxide is extremely slow relative to the other paint removal methods.

It should be noted that these strip times are for one worker and/or delivery unit and are for comparison purposes only. The operational strip rate could be enhanced for these methods through the application of additional workers and/or delivery units. Also, use of turbine systems rather than hose and nozzle delivery systems would increase the blasting strip times by a factor of seven.

Substrate Damage

The comparison of substrate damage presented in this section is a qualitative assessment of the potential harm a particular paint removal method may inflict on a substrate. Also presented are the precautions necessary to prevent potential damage from occurring. The survey forms were not used as the sole source for this section because of the obvious bias introduced when asking a representative or manufacturer of a paint removal method process whether it causes substrate damage.

Table E-2 summarizes the potential substrate damage and the necessary precautions for each of the alternative paint stripping methods being considered. The most significant categories of potential damage were:

- Residual stress/cold-hardening
- Corrosion
- Damage of surface treatment
- Water intrusion

Strict control and proper use of blast parameters, media purity, and masking are currently used precautions in industry. The intrusion of blasted corrosive material, however, may be more difficult to prevent and therefore poses a significant potential risk.

Table E-2 Substrate Damage Caused by Alternative Aviation Paint Removal Methods

Paint Removal Method	Potential Harm to Substrate	Precautions to Substrate Damage	Other Substrate Limitations
Mechanical			
Plastic Media	• media intrusion • residual stress, crack growth	• masking • precise calibration and control of parameters	• lightning suppresion foil tape
Wheat Starch	• media intrusion	• masking	• None
Sodium Bicarbonate	• media intrusion • corrosion	• masking	• None
Carbon Dioxide	• cold-hardening, crack growth • composite fiber erosion	• use with paint softener or other method (flashlamp)	• > 0.032 inch Al • No composites
Ice	• none	• none	• none
Thermal/Optical			
Lasers	• upper layer of composite damage	• feedback control	• none
Flashlamps	• heating of substrate	• energy control	• none
Solvent			
Non-methylene Chloride Based	• hydrogen embrittlement of magnesium, high strength steels	• masking	• none
Other			
Combined Water and Solvent	• water intrusion	• masking	• none

Environmental Impact

Because of the effect of environmental factors in creating the need for alternative paint stripping methods, this section is of special importance. The information summarized in Table E-3 tries to present any usage and disposal environmental hazards associated with each method. There are several items of note:

- The use of environmentally hazardous paint removal materials was generally avoided.
- The removed paint waste contains toxic substances which are present regardless of the paint removal method used.
- Separation techniques are generally required to separate the removed paint waste from the paint removal materials.

Table E-3 Environmental Effects of Alternative Aviation Paint Removal Methods

Paint Removal Method	Hazardous Media Ingredients	Process Byproduct	Amount of Spent Waste Produced *	Waste Disposal Methods
Mechanical				
Plastic Media	none	*paint chips *unusable media dust	8000 lbs per 25,000 ft2 stripped	separate paint chips from media
Wheat Starch	none	*paint chips *unusable media dust	< 8000 lbs per 25,000 ft2 stripped	separate paint chips from media
Sodium Bicarbonate	none	*paint chips * sodium bicarbonate and H_2O mixture	24864 lbs (sodium bicarbonate	remove paint chips from mixture
Carbon Dioxide	none	*paint chips *CO_2 and H_2O	see footnote	disposal of paint chips
Ice	none	*paint chips *water	see footnote	disposal of paint chips
Thermal/Optical				
Lasers	N/A	*paint chips and vapors	see footnote	vacuum vapor recovery organics burned inorganics dryscrubbed
Flashlamps	N/A	*paint chips and vapors	see footnote	vacuum recovery of paint chips and vapors
Solvent				
Non-methylene Chloride Based	Formic Acid	*paint/solvent mixture	125 gal (solvent)	remove paint from solvent
Other				
Combined Water and Solvent	none	*paint, water, and solvent mixture	125 gal (solvent)	remove paint from water and biodegradable solvent

Note: It is estimated that a total of 6.25 ft2 of paint will be produced regardles of method

Table B-4 Health Impact of Alternative Paint Removal Methods

Paint Removal Method	Health Hazard Data	Special Protection Required	Special Precautions Required
Mechanical			
Plastic Media	• particle/air blast • dust inhalation • noise	• full protective clothing including air fed respirator	• adequate ventilation • avoid blast
Wheat Starch	• air blast • dust inhalation • noise	• full protective clothing including air fed respirator	• adequate ventilation • avoid blast
Sodium Bicarbonate	•none	• goggles • gloves • respiration protection • noise protection	• adequate ventilation • avoid blast
Carbon Dioxide	•CO_2 is an asphyxiant •none	• goggles • gloves • respiration protection	• adequate ventilation • avoid blast
Ice	• media blast, cold temperatures • noise	• noise protection	• avoid blast
Thermal/Optical			
Lasers	• N/A, automated • high intensity light	• eye protection	• avoid work area while in operation
Flashlamps	• none	•none	• unknown
Solvent			
Non-methylene Chloride Based	• avoid eye, skin, and clothing contact	• chemical face shield or goggles	• adequate ventilation • avoid spraying in confined areas
Other			
Combined Water and Solvent	• high pressure water blast	• goggles, gloves	• avoid blast

Health Impact

In addition to environmental impact, the effect on the workers using the paint removal process needs to be considered. The move to development of alternative paint removal methods was primarily caused by the suspected carcinogenic effects of methylene chloride paint strippers. This section focuses on worker health impact in three main areas: general effects on health, special protection required, and special precautions required.The information obtained

Table E-5 Stripping Costs for a Standard Area for Alternative Aviation Paint Removal Methods

Paint Removal Method	Cost of Required Media/Solvent ($)	Cost of Unrecoverable Media/Solvent ($)	Cost of Paint Removal Equipment ($)	Worker Protection Costs ($)	Substrate Protection Costs ($)	Labor Costs ($)	Waste Disposal Costs ($)	Aircraft Downtime Costs ($)
Mechanical								
Plastic Media	153,440	4,008	1,200,000	500	6,000	4,170	150	260,625
Wheat Starch	562,950	14,074	1,200,000	500	6,000	8,340	7,250	521,250
Sodium Bicarbonate	239,616	239,616	13,000	500	6,000	6,240	500	390,000
Carbon Dioxide	50,000	50,000	104,500	500	6,000	750,000	150	468,750
Ice	6,250	1,875	650,000	25	6,000	7,500	150	468,750
Thermal/Optical								
Lasers	N/A	N/A	Unknown	25	-	2,490	150	155,625
Flashlamps	N/A	N/A	250,000	Unknown	-	4,140	150	258,750
Solvent								
Non-methylene Chloride Based	1,500	1,500	1,000	500	6,000	4,200	7,630	292,500
Other								
Combined Water and Solvent	1,500	1,900	Unknown	500	6,000	6,960	7,630	435,000

regarding these three areas is summarized in table E-4. There are several points of note:

- Proper worker protection is required for most paint removal methods.
- The dry blasting methods require control of the dust.
- Carbon dioxide imposes worker breathing requirements.

Cost

The cost of purchasing and operating a paint removal system is another very important consideration. Even a system that is safe for the aircraft may be made uneconomical from the operating cost of hazardous waste disposal or the capital cost of expensive parameter control mechanisms. Table E-5 presents the results of converting the cost information available to a common basis for comparison. This common basis is the cost of removing from the standard surface area defined for comparison purposes in this section.

In this cost comparison of alternative aviation paint removal methods the relative importance of these costs

should be discussed. The major costs involved in most of these aviation paint stripping methods are the capital cost of purchasing the equipment, but with increased throughput the per aircraft paint removal cost of the equipment decreases. The use of solvent-only methods of paint stripping eliminates the capital cost but introduces the need to dispose of significant amounts of liquid waste products. The time efficient removal of paint is a very important factor and is driven by the lost revenue from the downtime of the aircraft.

APPENDIX F - ALTERNATIVE AVIATION PAINT STRIPPING METHODS SURVEY FORM

Please help us to evaluate your paint stripping system by answering the following questions. If you use, represent, or supply more than one paint removal method, copy and complete this form for each method.

1. Identification

   1.1 Name of paint stripping system: ______________________________

   1.2 Type of paint removal product you supply, represent, or use:

   1. [ ] media
   2. [ ] other paint removal material
   3. [ ] media delivery system
   4. [ ] other paint removal equipment

   1.3 Type of paint removal mechanism utilized by your process:

   1. [ ] mechanical
   2. [ ] thermal
   3. [ ] solvent
   4. [ ] other ______________________________________

2. Paint Stripping Effectiveness

   2.1 What kind of coatings, such as paint/primer, can be removed?

   ____
   ____
   ____
   ____

   2.2 What are the aviation painted substrate materials and physical geometries (such as engine pylons, tail section, etc.) that can be stripped safely of the coatings indicated in (2.1)?

Material Type	Thickness	Surface Treatment	Geometry

2.3 What is the optimum strip rate for your system (ft^2/min) per nozzle, turbine, or other delivery unit?

____
____
____
____

2.4 At the optimum strip rate, what is the media consumption rate (ft^3/min)?

____
____
____
____

2.5 What are the parameters and values needed to safely obtain optimum stripping capabilities?

Parameter	Value	Comments
____________	________	__________
____________	________	__________
____________	________	__________
____________	________	__________
____________	________	__________
____________	________	__________
____________	________	__________
____________	________	__________
____________	________	__________
____________	________	__________

3. Substrate Damage

3.1 What is the potential harm that your system may cause: (select with check mark)

[ ] Corrosion
[ ] Residual Stress
[ ] Media Intrusion in Aircraft Structures such as: engine inlets, skin fastener heads, joints, control surfaces, etc.
[ ] Pitting
[ ] Erosion
[ ] Structure Deformation
[ ] None
[ ] Other ______________________________

3.2 If damage or harm is existent, what precautions are necessary to prevent it?
Select with check mark.

[ ] Masking
[ ] Anti-Corrosion Additives

[ ] Computer Controlled Systems
[ ] Contamination Filters
[ ] Other________________________________

3.3 What aviation substrate may not be stripped using your method and why?

____
____
____
____

4. Environmental Impact

If you have the Material Safety Data Sheet, that conforms with OSHA Standard 29 CFR 1910-1200, for the stripping media just attach it to the survey and skip sections 5 and 6. If you do not, please answer the questions in the aforementioned sections.

4.1 What are the Hazardous Ingredients of the stripping media?

____
____
____
____

4.2 What are the materials and conditions to avoid when using this stripping media?

____
____
____
____

4.3 What are the hazardous decomposition products of the media?

____
____
____
____

4.4 What is the stripping system's waste disposal method?

____
____
____
____

5. <u>Health Impact</u>

5.1 Health Hazard Data

5.1.1 Routes of Exposure (select with check mark):

[ ] Eye Contact
[ ] Skin Contact
[ ] Inhalation
[ ] Ingestion
[ ] Skin Absorption

5.1.2 What are the signs and symptoms of overexposure?

____
____
____
____

5.1.3 What are the effects of overexposure?

____
____
____
____

5.1.4 Has NIOSH found this material to be a potential carcinogen?

[ ] Yes
[ ] No

5.2 Special Protection Information

5.2.1 Does the maintenance crew need (select with check mark):

[ ] Respiratory Protection.
What Type?

____
____
____
____

[ ] Protective Gloves
What Type?

____
____
____
____

[ ] Eye Protection
What Type?

____
____
____
____

[ ] Ventilation
Local Exhaust______________________________

Mechanical________________________________

Special
Other____________________________________

[ ] Other Protective Equipment
What Type?

____
____
____
____

5.3 Are there any special precautions to take with your system?

____
____
____
____

6. <u>Environmental and Health Impact (Continuation)</u>

6.1 What are the byproducts of your process?

[ ] Chemicals
[ ] Coating Chips
[ ] Contaminated Solid and/or Liquid Media
[ ] Other. Explain

____
____
____
____

6.2 What volume, ft^3, of byproducts are produced when stripping an 1 ft^2 substrate?

____
____
____
____

6.3 Is the media recyclable? [ ] Yes [ ] No

6.4 How much reusable media, in percentage, can be retrieved from the byproduct?

____
____
____

7. Cost Analysis

7.1 If the answer to (1.2) was 1 or 2, what is the cost of your media or other paint removal material ($/ft^3)?

____
____
____
____

7.2 If the answer to (1.2) was 3 or 4, what is the cost of your paint removal system ($) per nozzle, turbine, or other delivery unit? What is the useful service life of your system (years)?

____
____
____
____

7.3 What is the cost of worker protection as defined by the following categories? Refer to your answer to question (5.2).

Protection Type	Cost ($/person)	Service Life (years or uses)

7.4 What is the cost of precautions against substrate damage. Refer to your answer in question (3.2). Please indicate if this cost is included in the overall cost of the system.

Protection Type	Cost ($/person)	Service Life years or uses)

7.5 How many workers are needed to operate the system per nozzle, turbine, or other deliver unit?

____

____

7.6 What is the cost of disposing of waste generated by your paint removal method ($\$/ft^3$)?

____

____

7.7 What cost can be recovered by selling recyclable byproducts generated by your paint removal method ($\$/ft^3$)?

____

____

7.8 If you operate transport aircraft, what is the lost revenue of your aircraft when grounded for maintenance (cost of downtime in $/hour)? Please indicate type of aircraft.

____

____

8. Additional Information

8.1 Please send any other information that you feel would be useful in understanding the capabilities and applications for your product.

9. Government Statement

9.1 Can this information be released to the public?
[ ] YES [ ] NO

If no, what are the sections that you will allow the government to release to the public:

____

____

____

____

9.2 Any information provided to the Federal Aviation Administration shall be free of cost.

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